THE

HIGH-PRESSURE STEAM ENGINE:

AN EXPOSITION OF ITS COMPARATIVE MERITS,

AND

AN ESSAY TOWARDS AN IMPROVED SYSTEM OF CONSTRUCTION,

Adapted especially to secure Safety and Economy in its Use.

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Translated from the German, with Notes,

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WITH TWENTY-EIGHT PLATES, ENGRAVED BY MR. GLADWIN.

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TRANSLATOR'S PREFACE.

It is possible that the first impression of the English reader, on perusing the title-page of this work, may be that of surprise at being referred to the writings of a foreigner, and to the results of foreign experience, for information on a subject so essentially English as that of the Steam Engine. England is, it will be said, not only the birth-place of this machine, but the country in which it has gained all the progressive developement that has fitted it for its present magnificent sphere of usefulness;—the English have been the inventors and improvers, and are *par excellence* the manufacturers of the Steam Engine;—and, it may be asked, is it consistent with our national honour to be sent to another country for information on a subject allowed, almost by common consent, to be peculiarly and exclusively our own?

This inquiry is natural enough, but it has a very simple and satisfactory answer. The Steam Engine is not a machine whose principles of construction and action are invariable: it admits of many modifications; or rather we should say, the properties of steam may be made use of by many diversified methods to obtain the desired result,—the production of mechanical power; and therefore if it can be shown that any one of these, which offers the prospect of advantage in its application, has been neglected by ourselves as a nation, we need not be surprised if our neigh-

bours should step in before us upon the untrodden path, nor in such case need we be ashamed of receiving instruction from them, as they have been accustomed to receive it from us, but in a much greater measure, heretofore.

Now it cannot be denied that from the time of Newcomen down to a very late period, the attention of the English has been almost exclusively directed to that modification of the Steam Engine which depends for its source of power principally upon the *condensability* of steam, namely, the *low-pressure condensing engine,* in which a very moderate elasticity is used. The other great class, comprising that variety of engine which owes its efficiency to the *elasticity* of the steam,—the HIGH-PRESSURE ENGINE,—was, a very few years ago, scarcely known among us in comparison. While we have found the condensing engine studied carefully, treated of most voluminously, and manufactured by wholesale, we have deplored the neglect which the high-pressure engine has suffered;—we have looked in vain for information upon it; and we have scarcely been able to point to a solitary specimen deserving the name of an economical producer of steam power. Surely then, while we have done so little with this variety of the machine, we need not scruple to attend to the investigations, and to profit by the experience, of those who have done more; and it is on this ground attention is invited to the following pages.

It must be admitted that there are two varieties of the High-pressure Engine to which these remarks do not exactly apply; namely, the Locomotive and the Cornish Pumping Engine. These have, of late years, excited so much attention, and so much energy, industry, and talent have been devoted to their improvement, that we may safely leave them in their present hands. Each is, in fact, so completely a machine *sui generis,*—so distinct from the ordinary engine, as to require for itself independent treatment and special discussion. There is, however, as everybody knows, a large and most useful class of

engines, manufactured in great numbers for driving machinery and other technical purposes, and known in commerce perhaps more generally than any other kind by the name of High-pressure Engines. For example, a party requiring an engine for driving machinery in a situation where water was scarce, would not dream of ordering either a Cornish or a locomotive engine, but would purchase a simple non-condensing high-pressure engine of the kind ordinarily known under the name. It is this large class of engines which have been so much neglected; and although the present work contains much matter applicable to all engines in which high-pressure steam is used, and indeed also to the steam engine generally, its principal object appears to be to bring into notice and to improve the class above named,—the *commercial* High-pressure Engine.

It must startle English Engineers not a little to be told that the high-pressure engine is both safer and more economical in its use than the low-pressure condensing one; yet such is the declaration of our Author, who, according to his own showing, appears to have devoted more attention to the high-pressure engine than perhaps any other Engineer now in practice. On this account, if for no other, the work now laid before the public is worthy of a careful and impartial examination.

The claim the Author puts forward to consideration as an authority, on the matter he treats of, may be gathered from the following extract from his Preface. He says, "For the course of now about thirty years have I uninterruptedly laboured in the field of knowledge offered by the steam engine, and for the far greater part of that time my attention has been directed to the high-pressure variety. I have erected a considerable number of engines of this description, of various sizes, and from all these I have gained opportunities of gradually carrying out into actual practice the results of my experiments and observations. I have also had the advantage of a two years' residence in England, where the opportunity was afforded me of observing and experi-

menting upon hundreds of steam engines, of the most diversified kinds, and applied to the greatest variety of purposes: and more than all, I have found by experience that my endeavours to accomplish the improvement of the high-pressure engine have had a constantly increasing success. On these grounds I have reason to hope that I may not be considered incompetent to the task I have undertaken, and that my statements and reasonings may be received with confidence."

But these grounds for such an estimation of the Author's qualifications for his work are scarcely necessary; the book itself furnishes ample internal evidence in its own favour. We are at no loss to discover that the Author has had much practical acquaintance with his subject;—that he has improved to the utmost advantage all the opportunities of observation and investigation which his practice has afforded him;—that he has taken much pains to make himself master of whatever has been previously done or written by others;—and that he has brought to bear on his task a sound practical judgment, an acute and comprehensive habit of observation, a close and forcible method of reasoning,—and, above all, a candid and unbiassed mind, anxious to discover the truth, and never ashamed to confess a past error, or to change a previously expressed opinion, when such a course has been dictated to him by the results of subsequent experience and investigation. The ample and copious discussion given to every point of importance upon which difference of opinion exists, or which is complicated in its nature and difficult of decision, and the honest endeavour to present impartially the whole view of both sides of a disputed question, testify not only the extent of the Author's information, but the careful and impartial manner in which he has endeavoured to deduce correct conclusions from the knowledge he has gained, and his evident anxiety to put his readers in full possession of the reasons which have guided him to his decision.

The First Part of the work, it will be perceived, treats

of the High-pressure Engine generally. After a few articles of introductory matter, the Author proceeds, *first*, to examine the principal objections brought against the high-pressure engine, dwelling more particularly on that one which has proved the greatest obstacle hitherto to its more general use; namely, its alleged danger. The various causes tending to produce explosions of steam engine boilers are discussed at length, and proof produced, both from reasoning and from experience, that low-pressure boilers are not less liable to such destructive accidents than high-pressure, if only proper care is used in the construction of the latter. The errors often committed in the manufacture of vessels for the generation of high-pressure steam are pointed out, and many excellent remarks and considerations in regard to boiler and furnace arrangements in general will be found under this head. After noticing other objections as to economy, &c., the Author goes on, *secondly*, to show the peculiar advantages possessed by the high-pressure engine,—as, simplicity, compactness, cheapness, lightness, conveniences of various kinds in working, and particularly economy of fuel.

He then proceeds to enter into the detail of his subject, and to investigate at considerable length the circumstances to be taken into consideration in the construction of high-pressure engines.

The Second Part treats of the Boiler and its appurtenances, and the Furnace. It contains the discussion of these important subjects generally, and a full description of two kinds of boilers used by the Author for his high-pressure engines.

The Third Part is devoted to the *Engine*, for the general arrangement of which the oscillating plan appears to be preferred, its advantages being stated at length, and objections to it answered. The cylinder, piston, valves, and other parts of the engine pass under review, and the Author's opinions are further illustrated by a description of his own engines.

The descriptions in Parts II. and III. are in minute detail, and contain the developement of the views to which the Author has been led as to the methods of construction best adapted to secure the ends proposed; namely, safety and economy in the use of the high-pressure engine.

The FOURTH PART contains general remarks on the economical results of the working of the improved high-pressure engines as regards their consumption of fuel, with examples;—on the dimensions and proportions of the engine;—on its application to machinery of various kinds;—and on the use of the waste steam.

The Plates attached to the work, comprising upwards of a hundred figures, not only serve as copious illustrations of the Text, but also furnish complete working drawings of engines and boilers in full and elaborate detail,—sufficient to direct any ordinary mechanical engineer in the manufacture of the machines themselves.

It may be gathered from what is above stated that the object of the work is three-fold: *first*, to bring forward the merits of the high-pressure engine; *secondly*, to give the views of the Author as to the best means of overcoming the objections to the system, and securing the two great desiderata, safety and economy in its use; and *thirdly*, to exhibit these views embodied in the practical form of engines actually made, in which the desired requirements are confidently stated to have been attained.

The *merits* of the high-pressure system require no elaborate disquisition. If a simple cylinder, 8 inches in diameter, can be made to do as much work as can be done on another plan by one twice the size, encumbered with costly and complicated condensing provisions into the bargain, we shall not require much persuading to prefer the former, *provided that it bring no disadvantage in its train*,—provided, in short, that it is as *safe* and as *economical* as its rival. Here, therefore, comes the question:

Can we make the high-pressure engine equal in these respects to the ordinary condensing engine;—can we free it from the danger and extravagance generally supposed to be inseparable from the system? How far our Author has succeeded in determining this, the readers of the book must decide.

But it is by no means necessary to the character of the work for usefulness, that we admit the Author to have proved all his points. I believe there are many Engineers of equal experience and authority with himself who will differ from him in some of his opinions; but there are few who may not benefit by his practical, experienced, and well-digested views. The book has a merit independent altogether of the high-pressure discussion, in that it contains (as a glance through the Table of Contents will show) much matter applicable alike to all kinds of engines: it exhibits, throughout, an example of the application of thought and consideration to mechanical details, which is too little followed in works of the kind, but which must tell home to the practical man, even when perhaps the conclusions arrived at may fail to convince him. The Author comes before us in a plain honest way, not as a patentee seeking profit, or an enthusiast thirsting for fame,—not with wild fancies, novel projects, or visionary schemes,—but offering to the public the results of his long experience, down to the smallest minutiæ, without fee or reward. He does not appear even open to the charge of an attempt to bring work to his own manufactory, for his descriptions are so full and explicit that any workman of ordinary intelligence and capabilities may manufacture for himself from them. Indeed this has actually been done: engines and boilers have been made in many instances by other foreign Engineers from the descriptions in the original work, and have been found fully to answer the good qualities predicted of them; and I have reason to believe that the improvements will, ere long, be tested in this country also.

Some few passages in this work may seem too critical upon

English Engineers; and it may happen that our Author has occasionally not been well informed as to the merits of the cases he criticises; but it must not be inferred that because some faults of English Engineers have been noticed, therefore their high position has been at all disputed. The fame of English Engineering is not such as need fear criticism; but we must recollect that our faults as well as our merits are open to the view of the world, and until we are prepared to declare ourselves infallible, our over sensitiveness would be only an imitation of the ostrich, who buries her head in the sand, and straightway fancies herself invisible.

I have only a word or two to add as to my share in the present publication. The translation of a work of this kind, whose object is to convey technical information, ought, I conceive, to be undertaken in a somewhat different manner from that of writings whose principal value lies in their literary merit. In the latter the rendering must be as close as the nature of the two languages will permit, or the work becomes, in fact, more the Translator's than the Author's: but with the former, where the purpose is to present correctly the *matter* of the book independently of the *manner*, the object of the Translator must be to seize upon the ideas intended to be conveyed, and to put them in such a dress as will be most adapted to the technical character and language of the subject treated of, without much regard to the style of phraseology of the original. In the endeavour to accomplish this, I have not hesitated to take occasionally some liberties in the translation, sometimes departing widely from the literal rendering, but always keeping in view the more perfect adaptation of the Author's meaning to the ideas and language of English engineering science. I have used my own discretion in omitting such matter as seemed to me wanting in novelty or connection with the subject, and have in general much shortened the descriptive portions of the work, believing I was writing for those who did not need such minute detail as is given in the foreign copy. The original is enriched

with a great number of references; but as these are mostly to foreign works, I have omitted the greater part, as of little use to the English reader. I have, I think, somewhat improved the *arrangement* of the work, by dividing off the matter in a more systematic manner than the Author has done, and by numbering the Articles. I have also added a synoptical *Table of Contents*, which presents at one view a general idea of the subject matter of the Treatise, and by means of which, reference to any particular item is rendered more easy. The Plates have been carefully revised, and several errors, existing in the originals, have been corrected. Much of the credit of the improvement in this particular is due to the engraver, Mr. Gladwin. I am somewhat proud to say that the Translation has been approved by the Author himself, as well as by others who have had the best opportunities of critically comparing it with the original, and the best ability to judge of its scientific character. The part first published has been adopted by no mean tribunal, the Franklin Institute of Pennsylvania,* as a standard authority on the subject of the High-pressure Engine.

The original work was published in Germany in 1843, and the First Part, and part of the Second, appeared in English at the commencement of 1847. It is due to the Publisher that I should apologize for the delay in the completion, caused by failure of health in a distant clime, and a consequent protracted journey: I have gained, however, thereby, the opportunity of visiting the Author's manufactory, of examining his engines, and of making myself more thoroughly acquainted with his views. I trust that the latter portion of the Translation has gained sufficient by this to compensate for the delay of its appearance.

I cannot do better than close this introduction with the following modest passages from the Author's Preface:

"In the midst of urgent business and continual interruption, I write the present Treatise upon the High-pressure Engine,

* See 'Mechanic's Magazine,' No. 1250.

with a view to general utility;—may its imperfections be pardoned for the sake of the good object at which I aim. The field of High-pressure Engines is yet so uncultivated, and the state of our knowledge and experience is yet so imperfect with reference to the merits or demerits of these machines, now taking such an important part in the intercourse of the world, that every voice raised on the subject deserves attention, especially if it proceed from those who have not merely become acquainted with Steam Engines behind the study table, but have had practically to do with them, and have been actively engaged in their construction and improvement. I confess willingly that my voice has but little weight; but my hope is, nevertheless, that it may find a sympathising ear.

"If my work has great and numerous defects, I hope it contains much that is worthy of notice, and calculated to be generally useful. And so can I say, with the modest author of the Book of Maccabees,—

> 'And if I have done well, and fitting the story, it is that which I desired; but if slenderly and meanly, it is that which I could attain unto.
>
> 'For as it is hurtful to drink wine or water alone; and as wine mingled with water is pleasant and delighteth the taste; even so speech finely framed delighteth the ears of them that read the story.
>
> 'And here shall be an end.'"

WILLIAM POLE.

London, June, 1848.

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INTRODUCTION.

1. It would be superfluous here to attempt to enumerate the benefits which the steam engine has conferred upon mankind. It is matter of universal knowledge that all branches of industry have, since its introduction into use, made most important advances through its aid; and every day's experience shows it constantly extending its beneficial influence to new and important purposes, and lending its powerful assistance to the further advance of civilization. When we consider what the introduction of the steam engine has already done, we have the less difficulty in anticipating that this invention may yet be destined to achieve objects of whose magnitude and importance we can at present form but a faint idea.

2. On this account, it is greatly to be wondered at that such a noble invention has not been brought to a higher grade of perfection. When it is considered what multitudes of labourers have been working in the field of its improvement;—what variety of points in the system the improvers have directed their attention to;—what manifold opinions have been advanced;—and how many thousand means have been tried to gain the desired end;—it must

appear astounding that all these efforts have produced so little real knowledge with respect to the great desideratum,—the most suitable and appropriate means of employing steam as a moving power,—and have left the question, at what point to commence improvement in order to arrive at the greatest degree of perfection, still undecided.

3. Yet more inexplicable, however, is the fact, that among all that has been done, we find such a want of experimental information as to the comparative value of the different known modifications of the machine by which the power of steam is made available; so few comparative experiments conducted in a scientific and impartial manner, which might tend to award to one system or another its relative degree of superiority, and so to lead to a determinate conclusion respecting this important element of the problem.

Up to the present time we find only a few scattered experiments undertaken by isolated individuals or by industrial associations; but this little does not suffice, and we can only hope to arrive fully at the wished-for object when the question is made a national one, and when a national purse will be available in order to secure a set of investigations, of proper extent, and made with a degree of care, leisure, and philosophical knowledge, commensurate with the importance of the design. The labours of those isolated individuals who have given their attention to the subject, have been frequently restricted to theoretical reasonings and calculations, which, often being biassed by prejudice, party spirit, or egotism, or as frequently proceeding from untenable hypotheses, have

not only failed in the desired object, but have tended yet further to increase the range of existing error: and when the labours of such have been of an experimental kind, they have generally had too limited a character, and have stood too wide apart, to throw much light upon the matter, or lead to any satisfactory general conclusions. Isolated individuals are seldom possessed of the proper means for the perfect attainment of their well-intentioned ends; while those who have the best opportunities and capabilities for the work, are usually withheld by the want of leisure, or other adverse circumstances, from prosecuting to a successful result the designs they might otherwise willingly undertake. The machine maker, careful for the most part after his own pecuniary advantage and the interests of his trade, frequently sacrifices to these objects the cause of science: the simplification of machinery tends to lessen the amount of his work and to diminish the number of its admirers, inasmuch as complicated looking machines more readily attract the attention of the purchaser than those of a more simple and less imposing appearance.[1] Moreover, the search

[1] This remark may probably be just in more cases than it is unjust; but we have among our British manufacturing engineers many brilliant exceptions. The mere mention of the names of Maudslay and Field, Rennie, Miller, Fairbairn, and others of similar character, would show that the spirit of investigation is not always damped by such considerations as those mentioned in the text. The following extract from 'A Treatise on the Cornish Engine,' by the translator of this work, bears closely on the point insisted on.—Tr.

"It is necessary to say something of the relations which subsist between the mining adventurer, the engineer, and the manufacturer of machinery in Cornwall, as their respective positions are somewhat peculiar, and different to those which obtain in the rest of the kingdom; and to this peculiarity may be traced much of the opportunity of improvement which has been afforded.

"In London and in the country generally, parties who require steam engines

after truth is beset with so many difficulties, and yet oftentimes the discovery, when made, appears so simple and of so little merit, as to offer but small inducement to

are accustomed to apply for them directly to the manufacturers, who thus become the *designers* as well as the makers of the engines; or if a civil engineer intervene, it is usually only to the general arrangement of the works that he directs his attention, leaving the details of the construction of the engine to the manufacturer, as before. The *management* of the engine, when erected, is intrusted (except in the cases of large works where a managing engineer is specially engaged) generally to the engine-man, or to parties having but little claim to the acquirements necessary for its skilful and economical performance.

"But in Cornwall things are otherwise arranged. There is a class of men, known by the name of *engineers*, who have no connection at all with the manufacturers, and whose sole and proper occupation it is to take charge of the steam engines upon the mines, and to design and superintend the manufacture of new ones, when such are required. The manufacturers do not pretend to be engineers, and would on no account undertake to supply engines,* except through the intervention and under the direction of some of the engineers.

"Thus every mine has its engineer, who has absolute command over the management of the engine upon the works, and to whom the credit or discredit which may arise from the working of the engine consequently belongs. If alterations or new engines are called for, the designs are made by the engineer of the mine, who procures estimates of them from the manufacturer, and superintends the due execution of the works.

"The advantages arising from this separation of the offices of the engineer and manufacturer are too important to be overlooked.

"A manufacturer has generally too much to attend to in the arrangements of his workshop to be able to devote much time to consider the improvement and watch the working of the engines he makes; and the matters which of necessity engage his daily attention are generally of too pressing and harassing a nature to allow of much study being given to the principles of what he is doing. Hence (although we know there are many honourable exceptions to this rule) we find that too frequently manufacturers are content to imitate the examples of those who have preceded them, and that what alterations are

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* *I. e.* for the mining districts: it is not uncommon for the manufacturers to undertake contracts on their own responsibility for other parts of the kingdom, or for abroad.

those who would seek for themselves; while in occasional instances the impediments of party feeling, a fear to deviate from the beaten track, or a bigoted attachment to some favourite principle in fashion at the time, all tend to discourage the hope of a speedy attainment of the desirable end by private and isolated endeavours.

Notwithstanding these discouragements, however, it is yet the bounden duty of all individuals to record and publish what they are able to contribute to the general stock of information, as by so doing they will at any rate furnish a collection of facts which may be of essential service in future investigations.

4. No one will dispute that heretofore too little has been done with the High-pressure Engine to determine

made, are only such as are suggested by the necessity of the case, and adopted often without due consideration.

"But in Cornwall the *engineers* are able to devote their whole attention to the improvement of the engine, unharassed by the cares of the manufactory, and are ever alive to the consideration of all circumstances connected with its action which can influence its duty: they have opportunities of trying experiments with a view to improvement, which it would generally be impossible for a manufacturer to undertake; and when they find these successful, they have the power to extend their application and see the effect of their working.

"Another circumstance which is also very favourable to the execution of the plans of improvement projected by the engineer is, that models are not generally charged for by the manufacturers. The expense of patterns is often a great barrier to the progress of improvement, by enhancing the cost of experiments on a large scale; but in Cornwall this does not operate, for (unless in particular cases which form exceptions to the general rule) this expense is borne by the manufacturers, and the engineers are free to make what alterations or experiments they please, without any direct charge being made for the necessary models.

"There can be no doubt that to this state of things is owing much of the improvement which has been made in the Cornish engine;—more perhaps than to any other cause, with the exception of the introduction of the duty reports."

its true value and place among the range of varieties of the steam engine. Its discussion, up to the present time, has been mixed up with so many diversified opinions, and replete with so much that is erroneous, unscientific, and contradictory, that it has only served to perplex the matter more and more, and to disgust the industrial community at large. The subject is beset with so many wants,—is yet so loosely treated in its philosophical bearings, and its practical application so imperfectly understood,—that experiments and researches of even the most ordinary character need no apology for their publication.

The English have in a great measure assisted in bringing this form of engine into discredit, if not by open attacks, yet through the bad construction and arrangement of their engines;[2] and it would have stood a chance of again passing into oblivion, had not the French, at a late date, bestirred themselves to prevent its downfall by examining and making known its advantages, and by a series of gradual improvements in its construction. America and France remain the only supports of the system; while in Germany but little interest has been excited in its favour, and its defenders have been, in Anglican fashion, openly opposed and condemned. The high-pressure engine has generally been conceded only a very limited field of application, and considered as only applicable to a certain range of objects. The late introduction of railways, and the great interest excited by them in all quarters, seem, however, now about to place the principle of the high-pressure engine in a

[2] This remark is a little tinged with the usual prejudice of the author against England; but we must confess it is not altogether devoid of truth.—Tr.

higher point of view. It is generally found, that a subject which has lain for a time dormant, has on its revival been taken up with greater zeal than before; and thus it is we now find that in England, so long exclusively the country of the WATT engine, the high-pressure plan is occupying the attention of engineers, and furnishing employment for the workshops throughout the land. The locomotive engine is now the watchword; information on the subject rises in value, and improvements and alterations succeed each other with unwonted rapidity. Thus England appears again about to become the mart for the high-pressure engine, and all now look to that enlightened nation for the perfect dispersion of the obscurity in which the subject has heretofore been enveloped.

5. The principal object of this my work will be to make known a series of experiments and observations undertaken by me; partly on engines which I have constructed for various establishments, partly on two which have been working daily under my own eyes;—to specify the researches that have occupied me uninterruptedly for a long term of years, with their unsuccessful as well as their successful results;—and to exhibit the train of ideas in reference to the improvement of the machine, which I have deduced from the whole. My objects have been, in the first place, to lessen, or rather entirely to remove, the dangers supposed to attend the use of high-pressure steam; and, secondly, to discover a plan of construction on the simplest possible principles, which should always correspond with, and be adapted to, the work to be done by the engine. In order to make myself intelligible to

those classes who are not skilled in the higher branches of physical and mathematical science, I have avoided as much as possible all calculations of a complex nature and of doubtful utility, especially such as are based on simple hypotheses, and not upon positive truth. I well know the danger of treading on such uncertain ground, and I have therefore restricted myself to drawing simple conclusions from simple experiments, and to forming, from these conclusions, simple rules for practice. If these do not always bear the stamp of high mathematical rigour, I dare assert that they are not of the less practical value, for I have never known them to fail in the whole of my experience as a manufacturer of high-pressure engines. And who would presume, after all, to deduce leading rules from theory in the present imperfect state of physical knowledge as applied to the steam engine? Mathematics can do nothing until a correct observation of nature paves the way for its application; and of what use are pages filled with algebraical formulæ, if after all we must, in order to go securely, adapt our results to our circumstances, which comes, in fact, to nothing but working *ad libitum?* While I have occupied myself with the actual construction of steam engines, I have always found, that if a sound judgment is brought to the task, but little calculation is necessary in order to accomplish a wished-for end. I have scarcely ever made engines similar to each other, but all for different purposes; I have had a manifold variety of circumstances to deal with, and not unfrequently difficulties to overcome which have led me out of the accustomed track; but I have ever found myself able to attain the most desirable results by the most simple means.

6. I hold it to be positively injudicious to recommend a certain form and construction of the high-pressure engine as an invariable standard. To a practised engine-maker a hundred different varieties ought to be at hand. He will, if he works wisely, strive to adapt these with practical skill to the purposes for which the engine is destined, and in all cases will endeavour to secure to the utmost extent the simplicity of the whole; for simplicity not only lessens the cost of construction, but makes the work more durable,—saves a considerable load of resistance,—increases the useful effect,—economizes fuel,—and tends to show to advantage the desirable properties of this kind of engine. Such an engineer will have the credit of stepping beyond the ordinary routine, and of elevating the profession of which he is a member.

I shall hereafter have occasion to show, that in order to attain the utmost simplicity, the general principles, as well as the details, of the high-pressure engine, may bear similar modifications without disadvantage; and I shall give designs of suitable arrangements for some of the most useful purposes to which steam engines are applied.[3]

[3] I have often been surprised to find how little attention is paid to this point in England. I have constantly seen there the most absurd combinations of engine and machinery: for example, one of the most common is that of working pumps by a rotatory engine. Here a rectilineal motion is first changed into a circular one, in order to be converted into a rectilineal one back again! In steam flour-mills we see engines at a distance from the machinery, and burdened with cumbersome fly-wheels, when by proper arrangements the momentum of the stones might render but small ones necessary, or in many cases might dispense with them altogether. Perhaps some of the English engineers adopt the vulgar error that a fly-wheel increases the power of the engine! But more of this hereafter.

[This allegation is, we must confess, but too true. When a manufacturer has made what is called "a set of patterns" for an engine, he is but too apt to make that form of engine serve for all possible sorts of purposes, without

much attention to the propriety of the adaptation. This saves him expense, and gives him extra work in making the necessary connecting machinery. Some excuse may be found for using a rotatory engine for pumps, inasmuch as a steadiness of motion is thereby attained which it would be difficult to secure with small engines working rectilineally. With regard to the last paragraph of the note, we are sorry to add that the scientific and engineering literature of our country shows but too many instances where persons may be found to propagate and defend the doctrine of either gain or loss by the fly-wheel, or of loss by the crank or connecting-rod, or in short any other absurdity. Let us hope that the light of science is now so far spreading amongst us that these blots on our philosophical character may soon only be matters of history.—Tr.]

PART I.

ON THE HIGH-PRESSURE ENGINE GENERALLY.

7. If we are to believe the accounts on record, that the first idea of the steam engine was suggested to the Marquis of Worcester by the blowing out of a cork from a flask of water which he had placed in too strong a heat, it is not easy to conceive how this accident could have led to the invention of engines working by condensation, which are mentioned in history as the first existing, and which Captain Savery brought into actual use. It seems much more probable that the result of the suggestion must have been a *high-pressure engine*, in the same manner as, at a later date, the bursting of a gun-barrel by steam, suggested to Oliver Evans the first idea of using high-pressure steam in his engines.

8. It is still more inexplicable that the high-pressure engine came so late into the field, and that nearly a whole century elapsed before this most simple method of applying the power of steam was brought prominently into notice.[1] The attention was confined almost ex-

[1] The explanation of this may probably be found in the fact, that it was so difficult in early days to make vessels and joints sufficiently strong to withstand

clusively to the production of a vacuum by condensation, in order to make use of the atmospheric pressure, or of steam of very low elasticity. A multitude of inventions have been called into being with reference to this plan, and it cannot be denied that great advances have been made in its improvement; so that the later built engines on this principle have become most perfect machines, and their application has in consequence been greatly extended. The names of a host of inventors have become illustrious in this field of discovery. The knowledge of the physics of steam has made much progress, and the general view of the subject has become much enlightened; yet no one, for so long a time, has dared to venture out of the beaten track, and to strike out for himself a new and successful path of exertion. To Oliver Evans was it reserved to show the true value of a long-known principle, and to establish thereon a new and more simple method of applying the power of steam; a method that will hereafter be greatly amplified, and will remain an eternal memorial to its introducer. The long delay of this revival affords a remarkable example of truths often shown by experience, namely, that the most plain and simple discoveries are generally reached through a labyrinth of complexities, and that even master minds are not free from the influence of habit and routine.

It is true that previously to the labours of Evans, Papin and Leupold had made use of high-pressure steam, and the latter proposed a real high-pressure engine in his *Theatrum Machinarum;* but the practical application

the high pressure. Savery, we know, experienced much inconvenience from this cause, and this it was indeed which principally prevented his engines from sustaining their ground.—Tr.

of the power was neglected, or at least we hear nothing more of the matter. Whether Oliver Evans was or was not aware of these suggestions is uncertain; but be this as it may, at all events he made the first actual high-pressure engine: his labours were crowned with success; and he showed clearly the great advantages to be derived from the plan. Indeed, to such perfection did he bring it, that Trevithick and Vivian, who came after him, followed but clumsily in his wake, and do not deserve the title of either inventors or improvers of the high-pressure engine, which the English are so anxious to award to them.[2] When it is considered under what unfavourable circumstances Oliver Evans worked, his merit must be much enhanced; and all the attempts made to lessen his fame, only show that he is neither understood nor equalled by his detractors.

9. The high-pressure engine is, however, in the present day, but little understood, and the great designs of its inventors but little appreciated: this is to be ascribed to the fact that its principles have never yet received the attention they deserve, although they have now been known forty years. Engines on this plan are treated as if already condemned: their advantages are generally doubted, or conceded only in a slight degree, and for certain applications; an outcry is made as to the great

[2] I give this as the author gives it, but not without protesting against the conclusion in the absence of proof in its favour. Unfortunately I am unable to procure data as to what Oliver Evans actually did, but the matter should be investigated, and I cordially recommend it to those able to take it up. Dr. Alban, when he mentions only Papin and Leupold, seems to forget that Savery's engines were, in the true sense of the word, *high-pressure* engines.—Tr.

danger with which their use is attended; and some of the opponents of the system have even gone so far as to insist that legislative interference ought to be exercised to limit their use. Other objections are, that they are less economical in fuel, are more subject to wear and tear, and require more lubrication than low-pressure engines; with other evils of a similar character. That some of these charges are occasionally well founded, cannot be denied; but it can be shown that the machines are liable to them only when unskilfully made; and that when constructed on proper principles, they are not only as free from objection as low-pressure engines, but in many respects are much superior to them.

Now what are the defects which high-pressure engines have hitherto laboured under? How are these to be remedied in their future construction? and what principles must be followed in order to secure the manifold advantages which the system possesses? I will endeavour to answer these queries, as far as lies in my power, in the following pages; but previously I will give a closer examination of the objections brought against the use of the high-pressure engine. From such an examination will more naturally flow a developement of the principles which should be adopted in order to remove these objections, and to insure the advantages that may be obtained by a proper construction of the engine and a suitable application of the steam.

EXAMINATION OF THE PRINCIPAL OBJECTIONS BROUGHT AGAINST THE HIGH-PRESSURE ENGINE.

10. *First Objection.*—This is the danger alleged to attend its use. It is asserted that vessels wherein high-

pressure steam is generated and contained, must be more liable to burst than such as are used for low-pressure. This proposition seems intelligible and self-evident, and it attracts at first sight the attention of those who are unskilled in such matters; yet it is only true in a qualified sense. Before, however, I proceed to investigate it more closely, I will venture to appeal to experience for the best evidence as to its value, and to inquire whether high-pressure boilers have been found more liable to explosion than low-pressure.

11. No instances occur in the history of the steam engine where a destructive explosion has happened to the engine itself,[3] even those worked to the highest pressure. The steam cylinder, and valve-boxes, the only parts of the engine exposed to the action of the steam, have always been found, even with a small thickness of metal, secure and durable. This is to be ascribed to the circumstance that these vessels are not exposed to any destructive agency, except the friction of the piston and valves, and this being nearly harmless, they remain in a constant state of safety without deterioration. The boiler or steam generator of the engine is the only organ exposed to mischief, and with this alone destructive explosions are found to occur. Who then will assert that only high-pressure boilers are subject to danger, and that low-pressure ones are secure? Such an opinion would be at variance alike with theory and experience, for we may consider,—

[3] A late destructive accident with one of Messrs. Samuda's engines was of this nature, caused by the giving way of the steam-pipe at one of its joints. Such accidents are very rare.—Tr.

12. (*a.*) Every boiler may become supercharged with steam when the quantity drawn off is less than the quantity generated, and when the safety-valves, in consequence of imperfections in their action or condition, do not properly perform their duty. Therefore, in so far as similar safety apparatus are used for both high and low-pressure boilers, they must be liable to similar interruptions in their working. Experience has shown this very often, and it has been found that even the vertical open-mouthed feed-pipes of low-pressure boilers, which act as escape-pipes when the boiler pressure is too great, (these are wanting in marine engines,) are not always secure.[4] If then an overfilling of the boiler with steam is equally possible in both high and low-pressure engines, both are liable to danger from this source; as the strength of the metal is adapted to the working pressure, and therefore the proper elasticity for which the vessel is constructed must be exceeded when such an occurrence happens. But there is an advantage on the side of the high-pressure engine, for the elasticity must be increased in a much higher ratio than with the low-pressure engine, before it overcomes the pressure at which the boiler is proved (usually three times the working elasticity); and therefore a much longer time will elapse before absolute danger arises. For example, in a boiler working at eight atmospheres, it will take a much greater lapse of time for the pressure to rise to twenty-four atmospheres, than it would to reach 12 ℔s. per square inch in a boiler working at 4 ℔s.; and these would be the points at which danger may be supposed

[4] Vide Dingler's 'Polytechnische Journal,' vol. xv. page 142.

to arise in the respective cases.[5] This gives a key to the experience of late times, that as great a proportionate number of low as of high-pressure boilers have exploded, as well in England as in America and France; and that among the latest instances, the accidents with the former have reached an alarming extent.

13. (*b.*) All boilers alike become gradually deteriorated by the working of destructive agencies upon them, particularly through the constant action of the fire without and the water within; so that the thickness of the metal may become gradually diminished, and at last reach a point at which danger may arrive. The worst of this evil is that the progress of the deterioration cannot be properly estimated, in consequence of many unfavourable circumstances that often happen, without either the knowledge or the fault of the person who has charge of the machine, and which are variable in the amount of their action, being more injurious at one time than at another. Such may be the following:

(1.) The overheating of certain parts of the boiler by the water standing at too low a level. Upon these places the metal, especially if iron, becomes speedily oxydized,[6] this effect taking place on both sides, from the action of the fire on the outside and of the water

[5] M. Arago notices this in the 'Echo du Monde savant,' No. 484. He characterizes the fear of high-pressure boilers as mere prejudice.

[6] Iron, long exposed to the action of fire, loses its fibrous texture, and becomes brittle and crystalline. Löwe found that wrought iron, long exposed at a red heat to steam, became crystalline, and that even the heat alone produced this effect without the application of moisture. It is not easy to find the cause of this phenomenon in any chemical property of iron; but be it what it may, the fact is undoubted, and results in a weakening of the tenacity and cohesive force of the metal.

in the inside, the latter arising from the decomposition of the steam by the incandescent iron, and the consequent attraction of the oxygen to the metal.

(2.) Too great an accumulation, either general or partial, of scale or earthy sediment in the boiler. These substances being bad conductors of heat, prevent, when in large quantities, the proper distribution of caloric to the water, or at least injuriously retard its transmission. The heat of the metal then increases to too great an extent, and may frequently rise to incandescence. Sometimes it happens that the layers of deposit arrange themselves in such wise as to leave interstices to which the water cannot penetrate: now if any of the adjacent portions become cracked, the water will suddenly find its way upon the hot metal, and will cause a local explosion, thereby loosening the scale not only from the part previously affected, but for a considerable distance round, and consequently increasing the contact of the water with the heated metal. This produces a rumbling commotion in the water, which, if the incandescent spot be large, may be in the highest degree injurious to the structure of the boiler. The steam thus suddenly formed augments the pressure, and hence again increased danger may ensue, particularly as the spot overheated will have been rendered more susceptible of damage. It has often been remarked that explosions were immediately preceded by the rumbling noise alluded to above. The high-pressure engine has in this respect also an advantage over the low-pressure, in that the sediment, when the elasticity is great, seldom attaches itself firmly to the sides of the boiler, but collects in a loose state, and is easily removed.

(3.) Damage to the boiler-plate by careless cleaning. Whoever has watched the process of cleaning ordinary boilers, and observed the forcible knocking, hammering, and chiselling of the foul plates;—whoever has remarked, to what ignorant and awkward men this work is intrusted, often without any superintendence;—and considers how the plates, perhaps already damaged by the fire, must in addition suffer from such violent handling;—will bear me out when I assign this process as frequently one of the principal causes of a speedy destruction of the boiler.

(4.) An unequal expansion between the several parts of the boiler, whereby damage often occurs, especially at the angles of the vessel. Those boilers which are constructed with fire-tubes or flues running through them are more especially exposed to this danger. Such tubes usually lie but a short depth below the water level, and therefore if the water falls short they soon become more heated than the external case of the boiler, and by the consequent greater degree of expansion, an injurious straining of the joints must necessarily ensue. The rents have been usually found at these joints when boilers of such a make have exploded.

But experience shows how little these destructive agencies have been heretofore attended to or remarked even by skilful parties; and we learn how difficult it is to discover their action or progress even when the attention is specially directed to them. We have instances where boilers have exploded immediately after examination, such as that of the American steam boat *Ætna,* and others of both high and low pressure.

14. (*c*.) Referring again to the possible accident of the falling of the water below its proper level, and the consequent incandescence of some part of the iron, we may remark that this heated portion of metal will, if at a sufficiently high temperature, generate hydrogen gas by the decomposition of the watery vapour. Hydrogen so produced has been long supposed to play an important part in steam boiler accidents, as it is conjectured it may inflame and explode inside the boiler. However, it must be recollected, that in order to produce this effect, the entrance of atmospheric air is absolutely necessary, and it is very difficult to conceive how air can enter in such quantity as to form an explosive compound with a large volume of hydrogen. The amount of air which may enter with the feed water is too insignificant to be taken into consideration, and an entrance of air through the usual safety-valves and openings of the boiler is only possible with low-pressure engines, but impossible with high-pressure ones for obvious reasons. With the former it may frequently happen, that during the working of the engine the pressure may sink below that of the atmosphere, and in this case air would easily enter,[7] while with the high-pressure engine no such effect can ensue.

But it is difficult to understand how any considerable quantity of hydrogen can accumulate in the boiler, since this gas, being specifically much lighter than the aqueous vapour, will naturally ascend to the top of the vessel, where the discharge-pipes are situated, and will thus be drawn with the steam to the engine before any great accumulation can take place. Moreover, it is very uncertain whether a gas

[7] Most engines have what is called a "vacuum-valve" for this very purpose.—Tr.

mixed with watery vapour would ignite at all; but be this as it may, the hydrogen gas theory is very problematical, and of late has been much more controverted than defended.

A more modern explanation of the occurrence of explosions from shortness of water in the boiler, is more probable, and more in accordance with our physical knowledge. It is founded on the supposition that the glowing metal may be suddenly covered again with water, whereby a great and instantaneous generation of steam would ensue,[8] in such quantity that none of the customary safety apparatus would avail for its timely discharge. It is easy to understand how the glowing plates may be suddenly re-covered with water: it may happen through a sudden diminution of the pressure in the boiler; or by too great an opening of the safety-valve; or by a suddenly increased demand for steam in the engine; either of which would cause the water in the boiler to start into a state of increased ebullition,[9] and consequently to flow over the plates. This view is corroborated by the occurrence of explosions immediately after the opening of the safety-

[8] Both iron and copper generate, when red-hot, a large quantity of steam: 10 lbs. of copper, heated sufficiently to glow in the dark, convert, according to Adam Hall, 1 lb. of water into steam, which under ordinary atmospheric pressure will occupy about 27 cubic feet.

According to Marestier, 4 lbs. of red-hot iron convert 1 lb. of water into steam.

Professor Johnson, of Philadelphia, found that iron at a white heat repelled the water, and that 9 lbs. of iron, at a dull red glow, scarcely visible by daylight, converted 1 lb. of water into steam. He also remarked that cast iron generated more steam than hammered iron, in the proportion of 9 to $8\frac{1}{4}$.

[9] It has been found that by a sudden removal of the pressure in a boiler, by opening the safety-valve with the hand, the water rises in the form of a cone towards the opening, and falls suddenly back when it is closed. This would inevitably cause the re-covering of the plates with water.

valve, when the low level of the water has been remarked, and an attempt has been made to relieve the boiler from the pressure of the steam within; or when a diminished velocity of the engine has previously denoted a diminution of pressure.[10]

15. Boilers which are fitted with imperfect water gauges or feed apparatus, are particularly liable to the evils of a partial exposure of the fire surface, and unfortunately these defects are but too common, particularly with high-pressure engines. The same liability to danger is also incurred where internal fire-tubes are inserted, or where the water space is too flat and confined, and is exposed in an injudicious manner to the flues. When tubes are introduced, they seldom lie deep enough under the water level, and are therefore soon left uncovered by an accidental slight depression of the latter; and if the water chambers are too confined, the water will be often driven out during violent ebullition. Marine and locomotive boilers are particularly liable to this. A steam boat boiler which burst at Hull (an account of the accident, with a description of the appearance of the boiler after the explosion, will be found in the 'Civil Engineer and Architect's Journal,' August, 1838, p. 283) furnishes an example of such an improper make. Both imperfections were united in its construction, and the collapsed fire-tubes showed that the metal of these parts had been overheated in consequence of the water being driven out of the too contracted surrounding chambers, and that by such overheating the parts were weakened, and at last suddenly

[10] Explosions have frequently happened after the first few strokes of the engine,—a strong corroboration of the hypothesis in the text.—Tr.

gave way to the pressure. It is much to be regretted that marine boilers are usually subject to the evil of too confined and too shallow a water space; because the ship's motion renders them particularly liable to the exposure of the fire-tubes: the use of sails increases the mischief, for when the ship has lain over on one side for some time, her righting or careening will throw the water back upon any portions of the metal that may have become overheated, and thus danger may ensue in proportion to the length of time the parts have been exposed and the degree of exposure.[11] Hence we find the majority of explosions occur on board steam boats, and proportionately but few on shore.

Now since all marine boilers, as well for low as high pressure, are liable, if injudiciously constructed, to similar dangers of the kind we have named above, no conclusion to the prejudice of high-pressure engines can be drawn from such accidents. Indeed of late years a general comparison has been in favour of the high-pressure system.[12] One reason why low-pressure boilers must, under the evils above mentioned, be less secure than high-pressure, is

[11] The motion of the water in the large box-shaped boilers, so much in use for marine engines, entails also danger from the concussion of so great a mass set in violent motion; which often tends to damage portions of the boiler, and loosen the rivets and other joints connected with it.

[12] *Vide* 'Echo du Monde savant,' No. 24, p. 178.

Up to the year 1834, only twenty explosions had occurred in America with high-pressure engines, while thirty-two had happened with low-pressure; and it is well known how common the high-pressure engine is in that country, particularly in the Western States.

At a later date, the proprietors of steam boats in North America have stated, in a memorial to Congress, that since the more general introduction of high-pressure steam, the number of accidents has not only not increased, but become lessened in an extraordinary degree.

that in the former the ebullition is much more violent, and the water thereby more liable to be expelled, whereas under a great elasticity the bubbles of steam generated take a smaller volume, the ebullition goes on more quietly, and therefore the danger is lessened.

The common chest form of low-pressure boilers with straight sides tends to increase the liability to the exposure of parts heated by the fire, especially if furnished with internal flues, as is generally the case with marine boilers. The large flat surfaces easily bulge out by an increased pressure within, and the consequent augmentation of cubical content causes a sinking of the water surface; after which the restoration of the elasticity to its original degree may throw back the water over the spots it formerly left, and thus the source of danger is at hand.

16. It will be in place here to refer to and examine some other hypotheses brought forward to account for the explosion of steam boilers: these will moreover serve to establish the point I have in view, viz., that the high-pressure system is not less safe than the low-pressure.

To these hypotheses belong, first, that of Jacob Perkins. It has been long known that steam may be charged with an excess of free caloric,[13] when the space in which it is contained is heated from without. This may often happen when the water surface in a boiler is too low, and the metal becomes consequently incandescent in certain places. The water present does not impede this effect, because, being a bad conductor, the heat is transmitted by it very

[13] Instances are on record where, by this means, fir has been inflamed when laid on the top of a boiler, and lead joints in the engine melted. I have often found tin soldered joints in the steam-pipe melted by overheated steam.

slowly downwards. Mr. Perkins finds that such overheated steam gains but very little in elasticity; but when water is scattered among it, and thereby becomes intimately commingled with it, (which may happen by an unusual ebullition,) the free caloric of the steam may be suddenly imparted to the water, and so may generate instantaneously steam of great elasticity in such quantity as cannot be carried off by the ordinary means of escape; and this may cause an explosion of the boiler.

This hypothesis is approved by many writers, but, for my own part, I cannot clearly see its force: for—

(1.) Should not the overheated steam escape into the engine as fast as it is created? and would it not produce such destructive effects upon the working parts as would cause immediate attention?

(2.) I do not understand how, with regular firing, the water could become so scattered among the steam as to produce the effect described. A sudden diminution of the pressure to a sufficient extent to cause a violent increase of ebullition, would be perceived by the action of the engine. The feed-pipe is always below the water level, and therefore it could not proceed from this source. And would it be so difficult for the heat to be distributed through the surface of the water, which is in constant commotion?

(3.) Some of my experiments with a steam generator made in London seem to tell against this doctrine. I have, by stopping the injection of water, kept the enclosed steam in contact with a metallic surface at a temperature of 800° Fahr., and yet no symptoms of an explosion appeared when the water was re-introduced; indeed a long-continued injection was necessary before

enough pressure could be obtained to set the engine to work again. If overheated steam attains so little consequent increase of pressure, how is it that when the water falls too low in the boiler the velocity of the engine generally accelerates? I have often remarked this to be the case.

(4.) It is scarcely probable that the small quantity of steam contained in a boiler can distribute so much heat as is supposed, since it is only the *free* caloric which comes in question. Mr. Thomas Earle ('Repertory of Patent Inventions,' Suppl. Jan. 1832, page 424) calculates that this could not be enough to generate steam in any dangerous quantity.[14]

17. A second hypothesis is that of Mr. Philip Taylor (Phil. Mag. N. S. No. II., p. 126). This appears to refer more to a forcible ejection of the boiler from its seating than to the actual explosion of the boiler itself. When by the closing of the chimney damper a quantity of coal gas is suffered to accumulate in the furnace, it may happen that by the opening of the fire door, or by other means, such a portion of atmospheric air may be admitted as will form an explosive compound by mixing with the gas; and if the fire openings are not large enough to allow of the sudden discharge, the boiler will probably be thrown from its seat. The occurrence of such explosions in badly constructed furnaces is by no means uncommon, but it is so easy a matter to provide against them by proceeding on proper principles, that they need not be further enlarged upon here.

[14] The particulars of this and other calculations to the same purpose are given by the Author in a note.—Tr.

18. Thirdly, Signor Morosi maintains the extraordinary theory, that the explosion of boilers proceeds not so much from the pressure of the steam within, as from a retrocession of the steam at the moment when the piston is at its point of rest at the top or bottom of the cylinder. The whole force of the steam, he asserts, is stopped in its motion, strikes back forcibly into the boiler, like the water in the hydraulic ram, and impinges as would a solid body on the boiler plates. According to his calculations, the impinging force is equal to that of a column of water which has the surface of the boiler for its base, and pressure and velocity equal to those of the steam. The effect of this in producing explosion he likens to well-known accidents occurring with pipes to convey fluids, and he proposes many ways of avoiding the evil; but I think my own opinion of the theory, and probably that of most practical men, will justify me in omitting them here.

19. Fourthly, The electric phenomena exhibited in the discharge of high-pressure steam have lately been called to the assistance of the discussion of the question of explosions. It is suggested for consideration whether such may not take place through a great generation and sudden discharge of electric fluid, or, so to speak, by an electric shock. MM. Jobard and Tassin support this theory,[15] and adduce in its favour the explosion of a boiler at *Vieux Valesse*, which exhibited no signs of the causes of explosion generally assigned. It appears to me, however, that the hypothesis hitherto rests upon too uncertain grounds to be admitted; and I conceive we ought to post-

[15] 'Echo du Monde savant,' 1841. No. 601.

pone allowing it a place among the causes of evil until it is more certainly proved, lest we should only increase the unfounded apprehension of danger, and thus bring undeserved discredit on a good cause.

20. It must be conceded that formerly high-pressure engines were subject to more accidents, in proportion to their number, than low-pressure; but this consideration is overborne by the fact that of later years a beneficial change has taken place in favour of the high-pressure system. I have already given my opinion that the cause of the danger was always to be found in the injudicious construction of the vessels, and not in the system itself. The idea of *high-pressure* steam is only a relative one, and only has reference to the comparative strength of the vessel against which the pressure is exerted. For example, the force of high-pressure steam against a vessel of small dimensions, is not greater than that of low-pressure steam against a proportionately larger vessel. In every boiler, steam of too high an elasticity for its proportionate strength may be generated when the precautions against such an accident are neglected; but it is possible to make vessels for steam of the highest pressure of such construction that they can suffer but little from it, and therefore have the advantage over the cumbersome boilers used for low pressure. The argument that high-pressure boilers will burst sooner than low-pressure, loses all its force except on the supposition that both are of equal size and equal thickness of metal. Hereafter, when describing my own boilers, I shall enter more fully upon this consideration: suffice it now to say that both kinds of boilers may be put on a perfect equality, under ordinary

circumstances, as regards their safety; but that danger first arises when the steam considerably exceeds its proper elasticity; and that in this regard a high-pressure boiler may be constructed with a greater probability of safety than one of the other kind, if proper consideration and knowledge be brought to bear in the design. It cannot be doubted that an overstrained low-pressure boiler becomes, so to speak, a high-pressure one, and must, *cæteris paribus*, be ranked with the latter in all considerations of the consequences of accident; since what is wanting in pressure is fully compensated by its great size and the great mass of its contents. Experience has never shown that the damage arising from high-pressure explosions has exceeded that from low-pressure, and late instances have rather tended to throw the weight of evidence on the other side.

I will now endeavour to point out what are the principal and fundamental errors in the construction of high-pressure boilers, which have led in so many instances to their destruction: these I consider to be the following:—

21. First. Many high-pressure boilers are constructed of *cast iron.*[16] This is a rotten and brittle material, which, when large and thick vessels are cast from it without the greatest precautions in the operation, is very apt to become blistered and hollow, and to leave, on cooling, large air spaces invisible from the outside, but exceedingly destructive to the strength of the casting. Moreover it is

[16] I have seen many such in England, especially in old engines: they consist of great cylinders of 3 or 4 feet in diameter, and 6 to 10 feet long, with internal fire-tubes.

very difficult to cast large vessels of perfectly even thickness in all parts; and if they are not so, they are liable to damage when exposed to heat, from the unequal expansion and contraction of the metal, and the irregularity of changes of temperature in the different parts. It is obvious also, that when such vessels do explode, the consequences must be frightful: they resemble bombs, and the massive fragments detached seldom fail to carry destruction wherever they fly. On the contrary, forged hammered or rolled iron, as generally used for boilers, in the shape of thick plates, is strong and tenacious, and by a proper calculation of its strength may be made to offer a great resistance to the steam: it is not so liable to sudden fracture as cast iron, but usually at first gives way locally, and shows defects that bring to notice the imperfect state of the boiler, and enable timely repair to be applied.

Copper is more tough and less liable to crack than iron, and is a most excellent material for high-pressure boilers: it has, however, a less cohesive power,[17] and therefore a greater thickness of metal is necessary to produce an equal strength; but since copper boilers never fly in pieces in case of explosion, it is not necessary to be too scrupulous in regard to this point. Even when the metal is thin, especially if the diameter is not great, the use of copper removes all danger of destructive explosion, since at most only a simple tearing asunder of the metal will ensue. But more of this subject farther on.

It was formerly thought that boilers of hammered iron plate possessed the advantage above ascribed to copper;

[17] According to Guyton Morveau, in the ratio of 302 to 549.

but later experience has shown that they are not entirely free from the liability to burst into pieces. Of course the greater or less degree in which the danger exists depends in a great measure upon the quality of the iron, and the nature of the bursting force.

22. Secondly, The *form* of boilers is not always the best. They ought for many reasons to be cylindrical, and, when large, to have spherical ends. This form withstands best the internal pressure, because the strain is equal on all points of the circumference. It is well known how often this rule is neglected in the manufacture of high-pressure boilers. Trevithick's original large cast iron boilers were indeed cylindrical, but the ends were flat, and without any secure fastenings. The same may be said of Oliver Evans's boilers, which had moreover the defect of internal fire-tubes, a fault also possessed by the boilers of the great Cornish pumping engines. Of late the plan of flat chambers, consisting of plates tied together at many points by strong bolts, has been tried; and Mr. Walter Hancock has taken a patent for such as applied to locomotive carriages, which he finds advantageous. Occasionally we see fire-tubes of a prismoidal form introduced into high-pressure boilers,—a plan fraught with the greatest danger. I have already spoken of the disadvantages attending the use of internal fire-tubes in general.

23. Thirdly, The boilers are of too large a size. The greater the content of a boiler, the greater surface it must offer to the pressure of the steam, and the greater danger it must be subject to. This truth is so self-evident, that it is incomprehensible how it should be so universally

neglected. The size of many boilers at present in use is truly astounding. I have not unfrequently seen them as large as 5 or 6 feet in diameter. Such boilers ought indeed to be named *exploders*, and the legislative restriction [18] as to the amount of pressure to be used with them is, as far as it goes, a salutary measure. Still better would the law stand if it began at the other end, and limited the size of the vessels instead of the elasticity of the steam within them; for such an enactment would be free from the objection of discouraging the use of high-pressure steam, now promising so much advantage to industry. We can scarcely hope, however, for the full realization of our wishes in this respect, unless a bold and enlarged view is taken of the system; for, as I shall hereafter show, the high-pressure engine cannot be made to display its advantages with steam under about six atmospheres' pressure. A compulsory enactment restricting the size of the generating vessels would tend much towards promoting the use of steam of such high pressures, and, by producing a necessity for acquaintance with the working of the engine, would undoubtedly further its real improvement.

It is indeed customary to give to boilers of great size a proportionate thickness of metal, but this helps the case very little; for experience has shown that thick plates, especially if of cast metal, are more liable to crack by the action of the fire than thin ones; inasmuch as the temperature of their two sides, exposed respectively to the fire without and the water within, does not quickly assimilate; whereby unequal expansion and contraction ensues. It is moreover a difficult matter to determine

[18] Probably a German one. I know of no such law in England.—Tr.

what the proper strength ought to be in proportion to the diameter and the pressure, and there is great difference of opinion among those who have given their attention to this point. It must also be noticed, that thick vessels tend more to retard the transmission of heat to the water than thin ones, although this fact seems often to have escaped the notice of engineers.

24. Fourthly, on account of the great size of the high-pressure boilers generally made, the steam and water space in them is mostly too large and too little separated, and does not bear any consistent proportion to the dimensions of the cylinder. The great quantities of steam and water tend to produce frightful consequences in case of explosion; the former by its great pressure and sudden expansion; the latter by its instantaneous conversion into steam by the removal of the pressure; as all the free caloric beyond the boiling point is spontaneously applied to the formation of new vapour.[19]

25. Fifthly, boilers are not generally provided to a sufficient extent with safety apparatus; and such as are employed are too often improperly constructed, and kept in bad order. I have seen many examples of their defects. It is scarcely to be believed, that many of the original Trevithick boilers were not provided with safety-valves at all! The regulations which have been promulgated in many countries, with reference to the examination of safety-valves and their preservation under cover, have a useful tendency, but, as I shall hereafter show, they often

[19] This is further enlarged upon and explained by the Author.—Tr.

fail in their object; since many accidental derangements may happen without the knowledge and in spite of the care of the attendants, and indeed may frequently occur immediately after the examination, and thus all watchfulness may be thrown away. The ordinary gauges for the pressure or temperature of the steam are only useful if constantly observed, and yet how seldom are they noticed by the majority of engine attendants. Certain contrivances have been invented which should ring a bell, or open a valve, or perform some such precautionary measure when the elasticity has risen to a certain height; but these only add complexity to a system which ought to be in the highest degree simple; and moreover, many of such contrivances are only applicable to low-pressure steam.

Metallic plugs, fusible at a low temperature, have been revived of late years, and their use is prescribed and regulated in France by law. But these are open to many objections: they often become dangerously softened before they reach the temperature at which they are destined to give way; and they only serve at best but as indices for the *temperature* of the steam, and as preventives against its overheating. Thus in case of a partial overheating of the metal of the boiler, and consequent surcharge of the steam with caloric, one of these plugs would become rather a disadvantage than otherwise, as it would, by its melting and allowing the steam to rush out, cause such a violent ebullition by the diminution of the pressure, as would probably bring about the very explosion it was the object of the precaution to prevent.

26. *Second Objection against the High-pressure Engine.* This is, that in the use of high-pressure steam much heat

is wasted, and therefore a greater expenditure of fuel is required than for low-pressure.

Although the fallacy of this opinion has been most fully shown in America, and later in France, by the most convincing and incontrovertible facts, the objection is still laid great stress on, especially in England, where the use of locomotive engines has, by their great consumption of fuel, rather increased than lessened the prejudice against the principle. The little that is said in its favour has but a remote chance of being attended to among such objections, and even the late extraordinary performances of the Cornish engines have either been disbelieved, or, where received in a better spirit, have produced but a trifling interest in favour of the use of high-pressure steam.

I will now give the statements which have formed the grounds of the objection alluded to, and investigate whether these are or are not of sufficient weight to render the allegation of serious import; and in so doing I shall principally call experience to my aid.

27. First. It is said that in heating any high-pressure steam generator, much heat must necessarily escape unused out of the furnace, since no heated currents which are below the temperature of the generator itself and its contents can give off heat to them.

Now I have found by experience that the evaporation of fluids will often draw off so much heat from bodies with which they are in contact, that these bodies may attain a very low temperature. Examples of this may be found in the cold experienced by the hand when volatile fluids are placed upon it;—by the conversion of water into ice by the evaporation of ether in vacuo;—by the

cooling of water in earthen vessels through moistening the outside;—and lastly, by the experiment of placing the hand at the bottom of a vessel of boiling water just removed from the fire, when almost the whole of the heat will appear to be drawn off by the ebullition.

These results seem to suggest the question whether the evaporating fluid may not bring the surrounding bodies, from which it draws its supply of caloric, down to a lower temperature than itself, and thus allow more heat to be withdrawn from the gases in the furnace than the objection supposes.

But it has also been found by experience that steam has been raised at a pressure of two atmospheres in one of Perkins's boilers, while the hand might be held in the smoke current passing off into the chimney; and I have myself seen the same thing. I have frequently placed my hand in the exit-flue of my boilers, and held it there some time without feeling more than a supportable and not disagreeable warmth; yet, however, it is a singular circumstance, and one which at present I cannot satisfactorily explain, that the thermometer showed, when placed in this current, a temperature equal to that of the steam in the boiler.[20] It has been asserted that a current heated as high as 400° Fahr. is necessary in order to produce a sufficient draught in the chimney, but my experience has shown me that a much less temperature will answer the purpose; and if this assertion were true it would evidently get rid of the objection we are considering, since low-pressure engines must then be subject to a

[20] It is well known to those who have had to do with the warming and ventilating of buildings, that a current of air of high temperature produces a very deceptive effect upon any part of the human body exposed to it.—Tr.

greater waste than high-pressure, in order to secure the draught in the furnace. It cannot be denied that in too many instances this loss does take place with both kinds of engines; but I shall hereafter find occasion to show how this arises, and to prove that it is unnecessary under a proper system of management and construction.[21]

M. Christian, of Paris, to whom we owe many of the latest researches in the theory of steam, found that equal quantities of water were evaporated in equal times, by the same fire, under various pressures and temperatures.[22] Now since the mechanical effect of a given quantity of water as steam when used to produce power varies in value according to the pressure, and always gives the advantage to steam of *high* pressure, so is it clear that in proportion to the power obtained there is not only no loss, but rather a gain in the economy of fuel.[23] I have often

[21] The best answer to this objection has been overlooked by the Author. It is found in the fact that such arrangements of the boiler and heating surface may and ought to be made, that the portions of the current impinging *last* upon the boiler before escaping into the chimney, may act upon the *coolest* portions of the water, namely, such as are newly introduced by the feed. This is admirably managed in the Cornish boilers: as see 'Treatise on the Cornish Engine' by the Translator, Arts. 129 to 131.—Tr.

[22] And so did Watt long before him. The Author gives in a long note the opinions of various writers on the disputed point of the quantity of heat in steam; but as the discussion is well known in England, I have not transcribed his remarks. He vouches from his own experiments to the correctness of that view of the case which is, I believe, most generally received in England;—that the *sum* of the sensible and latent heats is *constant* at all pressures, and equal to 650° centigrade.—Tr.

[23] I have investigated this point in the beginning of the third part of my work on the Cornish Engine, where my object is to show that the use of high-pressure steam, *per se*, is one of the causes of the great economy of that engine. This is demonstrated very clearly by a simple form of algebraical expression for the relation between the density and the pressure of the steam, and also by a practical arithmetical example.—Tr.

remarked that my engines worked with the least consumption of fuel when I had the throttle-valve least open, and consequently raised the pressure in the boiler higher than usual; and although the expansive working of the steam in the cylinder might be advantageous, this was not sufficient to explain the whole gain: we may at least draw the conclusion that an increase of pressure did not produce any disadvantage in such a case. It will generally be found that an engine works more economically when fully loaded than when working under power, and this is again in favour of the more economical generation of steam of high elasticity.

But certain experiments which I have made with a generator obtained in England for steam of very great elasticity, have shown in the most positive and unequivocal manner the fallacy of the objection; for I have been able to convert, with one pound of coal, 8 to 10 lbs. of ice-cold water into steam of from 600 lbs. to 800 lbs. pressure per square inch. During the evaporation there was so little heat passing away, that even after a long use of the apparatus I have scarcely found the 9-inch walls of the chimney warm: and I have now engines at work that lose very little; I have indeed found that the waste heat applied to the feed water in a vessel of extended surface, would not raise it up to 40° Reaumur.

With respect to the use of a blast in the furnace of high-pressure generators, I am inclined to think it an advantage, inasmuch as it tends to produce a more perfect combustion than when the fire is allowed to burn slowly. Too little attention is paid to secure this end in ordinary cases, and frequently a great deal of trouble is taken to remove an evil that has its source in a different cause from those

to which the remedies are applied. The most important principle upon which improvement in the furnace can be based has been shown by Herr Wagenmann. The smoke can only be completely burned by causing the perfect mixture of the gases over the furnace before an abstraction of heat takes place by contact with the comparatively cold surfaces of the boiler. If the current is allowed to cool, and to be mixed with a quantity of cold atmospheric air, admitted through other openings than the interstices of the fire, it is next to impossible that perfect combustion can take place. It is especially disadvantageous in this respect to have the furnace placed inside the boiler, a practice which, on account of its convenience, and its requiring no masonry, is usually adopted on board steam vessels. It is supposed to be an economical plan, because the heat which is in other cases expended on the brick-work, in this arrangement goes to heat the boiler; but the idea of its economy is a mistaken one, for the cooling of the fire currents against the sides of the boiler before perfect combustion has taken place causes more loss than the absence of the brick-work causes gain. The frightful clouds of smoke which pour from most of our steamers justify the explanation we have given of their almost universal want of economy.

M. Balcourt has put on record a very remarkable observation, made on a steam engine erected at New Orleans. He found that it would only do half its work when the fire-grate was raised six inches above its customary level. This is quite explicable on the hypothesis, that in the higher position the gases came in contact with the then nearer surface of the boiler before they were perfectly consumed; whereby they lost the heat necessary for their

incandescence, and imperfect combustion was the consequence.

It has been lately attempted to prevent loss of heat from the furnace of a boiler, either by passing the feed water through vessels exposed to the exit current, or by dividing the boiler into several parts which are acted upon by the heat in turn, the feed water being introduced into the last of the course. Both these plans have the advantage that the smoke current acts last upon the coolest water, and thereby affords the best chance of all the available heat being withdrawn.[24] Another important circumstance in favour of such arrangements is that the feed-pump may work with cold water, which obviates many evils constantly liable to arise when this important apparatus is made to work in hot water.

28. Secondly. Another argument made use of to support the objection that the high-pressure engine is not economical in fuel is derived from the great loss of radiant heat which these engines are said to suffer. Inasmuch as this loss from the surface of a heated body is greater as the surface is hotter; and inasmuch as many of the high-pressure boilers commonly constructed expose more surface to the outer atmosphere than they do to the fire, the argument must be admitted to have some force, especially as we so often see locomotive engines exposed carelessly to the weather. But it is easily shown that proper care in the construction and arrangements will remove the objection; and as I shall have ample occasion to enlarge

[24] Here we are again irresistibly reminded of the Cornish arrangements.—Tr.

upon this in a future part of the work, I shall say no more of it in this place.

29. Thirdly, another cause of waste of heat is said to be, that in consequence of the great pressure, there is more leakage of steam at the piston and joints of the engine, than with low pressure. This objection also depends, as to its value, entirely upon the state of the machine, and has no weight if the engine is well constructed and kept in good repair. It cannot, however, be said, unfortunately, that later engines have improved in this respect; and this, I think, is to be ascribed principally to the descriptions of pistons that have been introduced in late days, and that have often proved the reverse of improvements. Experiments of this kind are always useful in the search after truth; but we may profit by the experience already gained with the condensing engine, and we can never be at a loss for a perfectly tight piston if we adhere to the old hemp packing, and adapt it in a suitable manner to the wants of the high-pressure engine. As to the other joints, they present no difficulty but what may easily be surmounted by using the proper materials in a proper manner. And fortunately in the high-pressure engine we have to do with joints of much smaller dimensions, and therefore of much easier management than with low-pressure. My recommendation of the return to hemp pistons may, perhaps, at first sight appear a retrograde step, but I think it will be justified by what I shall hereafter advance, and that experience will corroborate all I assert in its favour. In the search after truth we often find ourselves compelled to relinquish what we have erroneously considered as better because

it is novel, and to return to older and more long-tried plans.

30. *Third Objection against the High-pressure Engine.* This is, that it does not realize the advantages of the vacuum obtained in condensing engines. If it could be shown that this vacuum was formed and maintained in low-pressure engines without sacrifice of power, the objection would have more weight; but experience tells us that partly through imperfect condensation, partly through the working of the air and cold water pumps, and from other causes of the same description, the useful effect of low-pressure engines is reduced from about 17 ℔s. per square inch absolute pressure upon the piston, to about *seven*, as made available in power obtained;[25] so that the use of condensation only in reality offers a gain of from $4\frac{1}{2}$ to 5 ℔s. per square inch, or one-third of the atmospheric pressure. It must then be admitted, that such a comparatively small gain is more than compensated by the advantages peculiar to the high-pressure engine; such, for example, as the greatly diminished prejudicial resistance; the simpler construction and smaller size in proportion to the power; the absence of so many pumps, pump-rods, and other machinery; the smaller mass to be set and kept in motion; the smaller proportionate diameter of the cylinder; the consequent diminution of friction of the piston, &c., &c.

The objection loses in weight as we use steam of higher pressure, and at seven or eight atmospheres is scarcely to

[25] Modern engines have much more *real* power than this: 7 ℔s. per square inch is used for the *nominal* power, which is generally much under what is actually performed. The argument, however, is good as far as it goes.—Tr.

be considered, because the surface of the piston becomes proportionately less as the elasticity is increased, and therefore the loss of the vacuum is less to be felt; while the advantages of the system are increased by such increase of elasticity. When the pressure used is too low, for example, only two or three atmospheres, as is most common, the loss may be important, and the advantages of the high-pressure system are not sufficiently developed to cover it. For instance, an engine of 10-horse power at two atmospheres' pressure, will require about twice as much steam as a condensing one of the same power: it must be of about the same dimensions, and by the want of a vacuum must be supplied with steam of a double elasticity to produce the same effect. Here, therefore, a power of ten horses will be sacrificed by the want of the vacuum; that is, as much as the whole power of the engine. But if a pressure of eight or ten atmospheres be used, and the principle of expansion applied, the proportionate loss, by the sacrifice of the vacuum, will be scarcely equal to 2-horse power out of ten,—a loss of very trifling weight when compared with the advantages possessed by such an engine over a low-pressure one. Yet more in favour of the high-pressure engine would the comparison be if we could substitute steam of sixteen atmospheres for that of eight; but unfortunately, through practical difficulties in the working of the machinery, our limits of available elasticity are at present too confined.

31. *Fourth Objection against the High-pressure Engine.* This is, that a greater consumption of oil and grease is required for lubrication of the piston, piston-rod, and valve apparatus, than for engines of low pressure. This objec-

tion is sometimes enhanced by the assertion, that the grease becomes volatilized at the temperature of steam of very high pressure.

Now since fat, animal as well as vegetable, only boils at a temperature of 220° Reaumur (527° Fahrenheit), and moreover does not, like water, volatilize at a heat under that of ebullition, it can scarcely be conceived how any loss can take place by volatilization in engines working up to eight or ten atmospheres, where only about half the above-named heat exists; and this pressure I never recommend to be exceeded. Experience has never shown the justice of the assertion, if we except a case mentioned by Mr. Perkins, where the grease (equal parts of good olive oil and Russia tallow) used for the piston was said to become partially decomposed; but this was under a much higher pressure than eight or ten atmospheres; and I must say in opposition, that I have never observed such a result when working up to forty atmospheres; but rather that an unusually small portion of grease, not the eighth part of what is necessary for low-pressure engines, was required.

I account for the loss of grease, when it exists, by waste merely, and not by evaporation or decomposition. The oleaginous particles become intimately mixed with the particles of water that lodge upon the sides of the cylinder, and are then blown away with the steam in its exit from the engine. This is the reason why the water which collects in the escape-pipes presents a milky or soapy appearance. It is a mistake to imagine that the black indurating substance that impure grease often leaves in the cylinder, and which is often so injurious both to the packing and the metal, arises from the decomposition of

the fatty matter; for this substance is nothing more than an induration of the fleshy particles left in impure tallow. It has been attempted to purify the tallow by the use of sulphuric acid in the melting, but this process frequently leaves free acid among the grease, which is very destructive to the parts of the engine.

According to my experience, a high-pressure engine requires much *less* lubrication for the packings of the piston and piston-rod than a low-pressure one. If it is once shown that the grease neither evaporates nor decomposes under the temperature, it is easily proved that the consumption *must* be less, inasmuch as the rubbing surfaces are so much smaller, according to the power. If the proprietors of high-pressure engines complain of the consumption, it must be because the attendants waste the material. The milky appearance of the water in the exit-pipes is common with low-pressure as well as with high-pressure engines, and, as already remarked, furnishes a conclusion against the decomposition theory.

32. *Fifth Objection.*—This is, that the working parts of high-pressure engines are more subject to wear and tear, and, as a consequence, that the engines themselves are more liable to interruptions in their working from the necessity of repairs.

This objection I can only allow to apply to those parts which are subject during their friction to an excessive degree of heat. But my experience has shown me, that with a pressure not exceeding eight to ten atmospheres the friction of such surfaces causes no disadvantage unless accompanied by too great an increase of pressure upon them; in such cases, for example, as the slide-valves when

injudiciously constructed, and the axes of oscillating cylinders when the steam is made to pass through them to and from the cylinder. I have in my earlier writings shown how these rubbing heated surfaces might be got rid of,[26] but the method is not without difficulty; and a longer practice in the manufacture of engines has convinced me that my former opinions required a change, and that the use of slide-valves was more convenient and more to be depended upon in many points of view than that of seat-valves. The latter are apt to be caused to leak by impurities in the grease,—by small portions of hemp from the packings of the pistons or stuffing-boxes,—or by other strange intruding bodies; and when this happens, great loss is occasioned, owing to the penetrating property of high-pressure steam, and the facility with which it will make its escape through the smallest openings. I do not deny that formerly I had much antipathy to slide-valves, principally because I at that time advocated the use of steam of a very high elasticity; but since I have been compelled, as an actual engine manufacturer, to adopt a cautious and secure line of practice, in order to be able to give the necessary guarantees for my work, I have devoted more attention generally to established and long-tried apparatus, and among them to the slide-valve; and in order to induce more certainty in the action of this essential organ, I have reduced and regulated the pressure under which my engines ordinarily work. I have been well satisfied with the results of my proceeding in this matter; for while I have realized in an ample measure the advantages of the high-pressure engine, I have avoided the inconveniences and

[26] Principally by the substitution of *seat-valves* for the *slide.*—Tr.

difficulties which in certain cases attach to the use of steam of very great elasticity.

It is inconceivable how the apparatus for transmitting the motion of the piston of a high-pressure engine to the machinery can be more subject to destruction, in regard to the durability of its joints, than in a low-pressure. If the power of each be the same, the machinery must have in each case equal strength: the stress to which it is subject is the same (or rather is less in the high-pressure engine, on account of the diminished prejudicial resistance, and consequently diminished total pressure required), and there is no reason whatever why any required strength may not be given to these parts; so that if there should be apprehension from the unequal action of the piston when expansion is used, the strength may be increased at pleasure. Can the gradually diminishing force of the steam of an expanding engine do more mischief than the great shock which must occur in low-pressure engines, owing to their increased resistance? Then every one knows what sudden concussions are produced throughout the machinery of a condensing engine at the moment when the air-pump discharges its contents, at which instant the whole pressure of the atmosphere is suddenly thrown upon the area of the pump. This shock is generally so forcible as to cause the whole machine to tremble, and to make itself heard for a long distance. Such a shock must undeniably tend to produce more damage to the moving parts than any cause which can be inherent in the high-pressure engine, whose simplicity and compactness are such as to give every facility for the attainment of the greatest security in its action, and the utmost durability in its mechanical arrangements.

It must, however, be confessed, that the construction of the high-pressure engine as usually adopted in England, has tended to bring discredit on the principle in regard to the durability of the machines. It has been frequently the practice, in order to gain an agreeable appearance and form, to fall into the great error of adopting the same proportions of the parts to each other as are used for the low-pressure engine: if these are regulated, as has often been done, by the diameter of the cylinder, according to the low-pressure calculations, the whole must of necessity be too weak, and subject to untimely destruction. The English have been much too negligent in their treatment of high-pressure engines, and thence it is that we cannot take their examples for our guidance with this machine, as we are wont to do with their low-pressure engines.[27]

ADVANTAGES OF THE HIGH-PRESSURE ENGINE.

33. Having now answered some of the most weighty objections brought against the high-pressure engine, and having shown in the course of the investigation that this

[27] This allegation is but too commonly true, or at least is not without good foundation. Such mistakes may be traced in the majority of cases to the (miscalled) *practical* method of working, so often approved and recommended by ignorant men. It has been too much the fashion to decry the study of *principles*, and to trust to what is called the "rule of thumb" line of practice, derived from experience *only*. This may answer very well of course while the party trusting to it confines his efforts to imitating what has been already done; but when any thing new has to be provided for, unless the Engineer has a knowledge of *principles* to guide him, and a capability too of reasoning upon those principles, he has no alternative but to blunder on till he arrives by hazard at the desired result. This would matter but little to any except the party himself, if his trials were private; but unhappily in most cases the unfortunate public have to pay for the schooling of their Engineer, and to suffer from the blunders his ignorance has caused.—Tr.

machine requires considerable modification from the existing methods of construction, in order to free it from its present defects; and having, moreover, referred to the possibility of effecting such beneficial changes;—I will now proceed to enumerate the peculiar advantages derivable from the use of this simple and valuable method of employing steam power; hoping thereby to turn the attention of future improvers as much as possible towards the laudable object of its yet more extended application. If what I have already said may contribute to turn these efforts in a right course, and to point out the most important principles from which improvement must proceed, I shall be amply repaid for the work I have undertaken; and I am the more induced to hope this may be the result, since it is upon the foundation here laid I have based the improvements which I myself have effected in the machine.

34. To the great advantages which high-pressure engines present over those of low pressure belong the following.

First Advantage.—They are much more simple, and, in proportion to their power, are of much smaller size, and much less weight. They are therefore less costly in the first instance, and less expensive to maintain in action; they are more compact, and occupy less room. For the cylinder is much smaller in diameter for an equal power; the length of the stroke may be also generally less; and, since condensation is not required, the velocity of the piston may usually be greater, by which means many parts of the machinery, particularly the fly-wheel, may be diminished in weight and dimensions. It is obvious also, that much of the heavy apparatus of the condensing engine

is altogether absent in the high-pressure one; such, for example, as the condenser with its appurtenances; the air-pump, the hot and cold water pumps, and all the complicated appendages necessary to attach these to the main beam of the engine. Moreover, all the troublesome and expensive arrangements for condensing water are dispensed with, such as cisterns, excavations, channels, and pipes, to convey the cold water to, and the waste water from, the machine. Many pistons and valves requiring constant watchfulness to keep them tight, are unnecessary in the high-pressure engine; and thus not only the trouble but the materials for packing and lubrication are saved. In the jointing of pipes much also is spared. The various parts are much less clumsy and awkward to manage, and therefore the engines are more portable, and their erection becomes much more convenient and easy. This latter qualification has caused their exclusive use for locomotives and steam carriages.

It must, however, be remarked, that all the above-enumerated advantages apply to the *engines* alone, and do not always refer in the same degree to the *boilers*. The dimensions of these do not follow the smaller size of the cylinder in the same proportion; but still, as a smaller actual quantity of water is required to be evaporated, they have their advantages when properly constructed. In the unscientific arrangements heretofore generally adopted for the generation of high-pressure steam, the boilers have been most formidable objects of attention, requiring enormous strength and weight of metal, and the greatest trouble in manufacture; but these inconveniences may be much reduced, as I shall hereafter show, by a more suitable method of construction.

35. *Second Advantage.*—The high-pressure engine sustains much less loss from the friction and other prejudicial resistances inherent in the engine itself, than is the case with the condensing engine. The rubbing surfaces are neither so numerous nor so large; there are not so many bearings and journals; several pistons are absent, and those that do exist are smaller. The fly-wheel is of less weight, and therefore the friction of its bearings is less. The air and cold water pumps, which consume so much power in the condensing engine, are wanting. The only pistons in the high-pressure engine are the steam piston and the feed-pump, and the friction of these is very insignificant in proportion to the work done.[28]

36. *Third Advantage.*—High-pressure engines do not require the constant large supply of cold water necessary for condensation. This, in many situations and under circumstances which often occur, is very difficult to be obtained; and even where it can be had, often requires extensive excavations, pipes and conduits, and frequently also apparatus for cooling the water discharged from the engine. All these arrangements increase to a very considerable extent the first outlay. Steam vessels also, which visit tropical climates, often find it difficult to obtain water sufficiently cold for efficient condensation. The advantages of the high-pressure engine in this respect have never hitherto been sufficiently estimated.

37. *Fourth Advantage.*—Although high-pressure engines

[28] Some paragraphs, which, in the original, follow here, I have incorporated with the *eighth* advantage.—Tr.

demand, when a considerable elasticity is used, a greater degree of care and accuracy in the fitting of the joints, in order to make them steam-tight, they yet possess this great advantage, that leakage is sooner discovered in them than in low-pressure engines. In the former a failure, or aperture, however small, is at once betrayed, and can be immediately attended to; but with the latter, leakages, especially of air into the vacuous space, may continue for a great length of time without discovery.

38. *Fifth Advantage.*—In the high-pressure engine, the operation of *blowing through* at starting, by which both time and steam are lost, is not required. The pressure of air in the engine, at the commencement of its motion, is rather an advantage than otherwise, as when expanded by the heat, it serves to assist the motion.

39. *Sixth Advantage.*—The use of high-pressure steam allows, at any time when desired, a temporary augmentation of the usual power of the engine, without any other preparation or alteration than that of a slightly increased production of steam in the boiler. All the parts are constantly in readiness to receive, and to apply, a higher pressure of steam. It is, however, not so with the condensing engine. The condensation is only adapted for a certain quantity of steam each stroke, and if a larger amount were to be thrown in, the consequence would be an imperfect exhaustion of the cylinder, which would neutralize any attempt to increase the power of the engine by an augmented pressure of the steam. It is on this account that the high-pressure engine is invaluable for locomotive purposes. The advantages we are now in-

sisting on may be best attained by making the boiler of such dimensions and strength as will suffice for an increased pressure of steam; and when this preparation is made, the ordinary working of the engine will be managed by a careful adjustment of the firing to a degree between maximum and minimum. Mr. Gurney proposed to use in the boilers of his locomotive carriages, steam of a high pressure, which was *wire-drawn* to two or three atmospheres in the engine by a diminution of the opening of the throttle-valve. When therefore he wished to increase the power of his engine, all he had to do was to open this valve a little wider, by which means he proposed to adapt his engine to overcome the ascent of hills. This plan of *wire-drawing* the steam is doubtless a favourable one in regard to economy.

40. *Seventh Advantage.*—High-pressure engines have also the great advantage, that the state of the packing of the piston, as to whether it is steam-tight, or to what extent leakage exists, may be easily discovered by the manner in which the steam blows out from the cylinder. In order to render this observation more convenient, I make a small opening in the discharge-tube, which is usually stopped with a wooden plug: when the stopper is withdrawn, the steam blows through the hole in the same manner as through the large tube itself, and can be observed accordingly. In low-pressure engines, it must be allowed that the greater or less heat of the condensed water gives an index of the same important condition, but this is neither so direct as the method just described, nor so much to be depended on; since the quantity or temperature of the injection water may often change, the

former depending, in fact, constantly on the state of the vacuum.

41. *Eighth Advantage.*—The high-pressure engine is more economical in fuel. This advantage is developed partly in the generation of the high-pressure steam, partly in consequence of its more suitable application to its purpose in the machine itself.

For the positive determination of the reality of this important but much doubted fact, we are indebted principally to the Americans and the French, who have paid more attention, theoretically and practically, to the high-pressure engine, than the English, and are therefore more competent judges in such a weighty matter.

But the advantage is not only proved by experience, but is deducible also from theory. It has already been long known that the temperature and elasticity of aqueous vapour increased in a ratio favourable to the practical application of high-pressure steam; and therefore it has been conjectured, as now is shown to be the fact, that engines on this principle ought to be more economical than those of low pressure. I have already (Art. 27) alluded to the subject of the caloric in high and low-pressure steam, and I may add here, that if it is proved that the former contains most free caloric, this is an advantage, rather than the contrary, inasmuch as the greater or less elasticity of the vapour is not the effect of its density alone, but also of its expansion by the free caloric it contains. In this regard, the saving of latent heat in highly elastic steam undeniably outweighs the disadvantage of a greater necessary supply of free caloric.

The expansion of high-pressure steam by its greater

content of free caloric has been occasionally doubted; but its greater proportionate useful effect, even when separated from all other causes of advantage that can occur in the machine, speaks in favour of the hypothesis. My experience has shown me, that in considering the effect of high-pressure steam, something more than the density must be taken into account; and the fact of its exceedingly great subtilty and penetrating power, in which respect it is beyond comparison with any other highly compressed fluid, as air for example, confirms me in this opinion.

It is usually considered that steam increases in volume by the addition of free caloric, in the same ratio as atmospheric air; that is (according to Bernouilli) about $\frac{1}{270}$ $(\frac{1}{267})$ of its original volume at freezing point, for each degree centigrade. But is not this proportion too small for high-pressure steam? My experiments, as well as those of others, lead me to think so, and I am of opinion, that if steam supercharged with free caloric could be used in an engine much economy would result. At present, however, such a plan could scarcely be tried without destruction to the packings and other working parts of the machine.[29]

42. Secondly, the peculiar economy of the high-pressure engine arises also from a more suitable application of the steam to its purpose in the engine itself: and this on the following grounds.

(*a.*) The steam finds less resistance to its action in this

[29] I do not quite see that the Author makes out his case conclusively in this Article; but I refer again to my own demonstration (see note to Art. 27) that the use of high-pressure steam, *per se*, is advantageous in regard to economy.—Tr.

engine; for on account of the great pressure, its motion to and from the cylinder is more free and rapid than in the low-pressure engine. In the latter the condensation proceeds gradually, and therefore at the commencement of the stroke the resistance to the piston is much greater than when the steam has had time to condense more perfectly.[30] This defect, which in my opinion is one of the causes of the loss of useful effect in condensing engines, has, I think, been generally too much neglected, and I will therefore explain my meaning a little more fully.

It is obvious that, in order to gain the full effect from the action of the steam upon the piston, the pressure opposed to its motion ought to be removed as quickly and as completely as possible, and therefore at the commencement of every stroke the steam remaining from the last one should be withdrawn with all possible rapidity. Now in the high-pressure engine this may be completely accomplished by the mere precaution of making the steam passages of sufficient size and allowing them to open quickly;[31] but in the condensing

[30] We may again refer to the peculiar advantages of the Cornish engine, where the *pause* before the commencement of the stroke is especially adapted to the removal of the defect mentioned in the text,—a defect very generally existing in the ordinary Boulton and Watt engines. The *lead* often given to the slide-valve of rotating engines also contributes in some degree to mitigate the evil.—Tr.

[31] I have often remarked in my steam engines (where the steam makes its exit from the cylinder with a pressure of about three atmospheres) the singular circumstance that at the moment of the exit of the steam, a grease-valve on the cylinder, opening inwards, *let in air;* showing thereby that the pressure within at that moment was less than that of the atmosphere. I explain this by the inertia of the steam, which, being once set in violent motion, continues it somewhat beyond the point where the pressure becomes equal to that of the atmosphere. This circumstance gives a satisfactory answer

engine there are several impediments in the way, which I will enumerate briefly.

(1.) The valve motion is much too sluggish. The apparatus is generally worked by an eccentric on the fly-shaft, and the opening is only fully completed when the engine has made half its stroke.

(2.) The exhaustion openings are usually made much too small in proportion to the size of the cylinder. I shall have occasion to speak further on this point.

(3.) The communications with the condenser are also too confined, so that the steam cannot pass away with sufficient rapidity.[32]

(4.) By the ordinary method of injection the condensation is not effected instantaneously, but gradually, by reason that the quantity of water necessary to condense the cylinder-full of steam must occupy some considerable time in passing through the injection cock. Therefore there remains a counter-pressure against the piston, greatest at the commencement of the stroke, and gradually diminishing as more water is injected and the condensation becomes more perfect. It is attempted to improve this state of things by increasing the injection opening, but this entails the disadvantage of requiring a greater quantity of water to be supplied and withdrawn than is proportionate to the quantity of steam to be condensed.

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to the objection derived from the supposed greater counter-pressure on the piston, and corroborates the asserted advantages of the high-pressure engine over the condensing one.

[32] These three defects of course may be rectified. In an engine which I altered in these respects, I doubled the velocity by this means alone. I shall hereafter give rules for the best proportions.

Thus may be explained, on the one hand, the imperfect vacuum observed in some engines; and on the other, the excess of the actual over the calculated quantity of condensing water necessary to be supplied.

From these and other causes we find about one-half of the total power of the steam absorbed in the condensing engine: *i. e.* out of 17 lbs. total pressure, only about 7 lbs. are made available for useful effect; while with the high-pressure engine, when properly constructed, I can vouch by my own experience, that only *one-fourth* need be so consumed. Others have sometimes found the loss greater, but I believe they have always been misled by the use of engines of an inferior description.

(*b.*) M. Christian, of Paris, has found by direct experiment,[33] that the loss of power consequent upon increasing the velocity of the piston is proportionately much less in the high-pressure engine than in the low-pressure; and that the mechanical effect in respect to the higher velocity is increased to a greater extent as the pressure used is greater. This is corroborated by the well-known fact, that the piston of a high-pressure engine may be driven at a great velocity (250 to 300 feet per minute) without entailing the loss which always ensues when the velocity of the low-pressure engine exceeds about 200 feet per minute.

(*c.*) The use of high-pressure steam allows the prin-

[33] *Vide* 'Traité de Mechan. industrielle,' by this Author, p. 345. His researches are very interesting, and I recommend them to attention.

ciple of expansion to be carried to a greater extent than in the low-pressure engine, without requiring the dimensions of the cylinder to be considerably increased. By the application of this principle a most important saving is attained; but that it cannot be carried out efficiently with low-pressure steam, is shown by the fact, that the sagacious WATT could not work it to advantage, and that WOOLF, who re-introduced it with success, used high-pressure steam in his engines. When the expansion principle is used with low-pressure steam, the effective pressure is so small that the cylinder must be greatly increased in size to give a certain power. To this cause may also be traced the failure of Hornblower's engines, which were expansion engines with low-pressure steam, and on which Woolf afterwards so much improved.[34]

(*d.*) The steam acts in a manner, so to speak, altogether *positive*, and is not robbed of all that valuable portion of heat which in the low-pressure engine is lost by condensation. On this account the steam, after passing from the engine, may be used again for a variety of purposes; such as for warming the feed water before it enters the boiler; for the purposes of cooking, heating buildings, drying, &c. In certain manufactories where large pans or boilers, drying apparatus, &c., require to be heated, the power of an engine may be obtained almost free of expense by adopting the plan above named.[35]

[34] For a further illustration of these remarks, see 'Treatise on the Cornish Engine,' Arts. 40 to 46.—TR.

[35] I have for the last twenty-five years directed my attention to this point, and have had the opportunity of contriving many uses, of greater or less

(*e.*) There is not so great a degree of condensation in the cylinder. According to my idea, the views generally adopted on this subject hitherto have been entirely erroneous. It is given as a principle, that steam at a high temperature is more exposed to condensation than when at a lower degree of heat, since the transmission of caloric from one body to another is quicker as the difference between their temperatures is greater; but it has been overlooked, that in low-pressure engines there exists a circumstance which appears to me to be a greater cause of waste of heat, and which I will endeavour briefly to explain.

In the low-pressure engine, the vapour in condensing gradually becomes attenuated before it finally leaves the cylinder, and by this attenuation it loses proportionately in temperature: further, the steam acquires by being thus cooled a tendency to rob the cylinder of the heat previously given to it by the steam newly admitted, and thereby to take into the condenser more free caloric than would naturally belong to its elasticity. That WATT, and subsequently WOOLF, overlooked this circumstance, is shown by their use of the steam-jacket, by which this disadvantage was naturally increased.[36] It has been often subject of astonishment why the quantity of water necessary for condensation should

importance, for the waste steam from the high-pressure engine: these I shall hereafter notice.

[36] We are yet much in the dark as to the precise nature and degree of the influence of the steam-jacket over the action of the steam within the cylinder of expanding engines; but it seems to be well ascertained that a casing of steam is absolutely necessary to the economical working of the Cornish engine. The experiments made upon it in Cornwall have just sufficed to establish this point, and no more.—TR.

always be found in practice greater than that given by calculation, and the error has generally been laid to the charge of leakage in the piston packing; but it seems to me that the fact is explained by the reason I have given. If then this abstraction of heat from the metal of the cylinder be allowed to exist, it is easily understood what a loss must be sustained by the newly entering steam which has to furnish the supply to compensate for such abstraction. When a steam-jacket is used, of course this loss falls upon the steam inside the jacket.

But, it may be asked, does not a loss of a similar kind also exist in the high-pressure engine? Certainly; but it must be considered that the surface of the cylinder in this engine bears a much smaller proportion to the volume of the steam discharged; and that the exit is too rapid, and renewed too quickly, to allow of any considerable abstraction of heat, which must be a work of time. Besides, this loss is less noticeable in engines where expansion is used, and where the steam is applied to other purposes after it has been discharged from the engine.

43. Having now set forth the principal advantages of the high-pressure engine, I must finally say a few words for the purpose of correcting certain mistaken ideas which are very prevalent, even among enlightened and scientific men, in reference to the source whence economy of fuel in the machine should arise.

It has been the general opinion that this source lay in the generation of the steam, and to this end have most of the later improvements been directed; while the engine

itself and the principles of its construction have been thought to have but little influence in the matter.[37] Now although I have certainly endeavoured to show that there is an undeniable advantage to be derived from the use of high-pressure steam, considered in respect to the economy of its production, and moreover that this advantage increases with the pressure employed; yet must I strongly protest against the erroneous idea, that the greatest improvement of the high-pressure engine is to be looked for in the more perfect arrangement of the apparatus for its generation. The advantages to be derived from the suitable application of the steam in the machine are to me so clear and obvious, that I have, in what I have done, had more respect to this point than to the economy of the boiler: it will, however, be found that in the details which I shall exhibit in the following pages, I have endeavoured to apply and carry out, to the utmost extent, all the principles of improvement I have hereinbefore laid down.

[37] It is worthy of remark, that nearly all modern inventions directed towards the improvement of the high-pressure engine, and particularly all those described in the latest English patents, have had reference to the boiler alone. This shows how little has been thought of the advantages which the engine itself may be made to afford.

PART II.

ON THE BOILER AND ITS APPENDAGES: AND THE FURNACE.

ON THE BOILER AND ITS APPENDAGES: AND THE FURNACE.

44. I come now to my own high-pressure engines; to describe their peculiar construction; to explain the grounds upon which I have founded my choice of this construction; and to exhibit the plans I have adopted for generating and using high-pressure steam with economy. I shall endeavour to describe these machines and the apparatus belonging to them in as exact and complete a manner as possible; and shall also set forth their advantages with all the impartiality I can command.

When in London, I believe I made use, in my engines, of steam of a higher pressure than had ever been employed before. Once I worked an engine, for the sake of experiment, to a pressure of 1000 ℔s. on the square inch; and it was found that under this tremendous pressure, the engine itself remained perfectly firm and steam-tight in all its parts. On a subsequent examination, it appeared that the packing had become somewhat singed *(gebräunt)*, and softer than usual;[1] nevertheless it retained the steam

[1] It is a general opinion that hemp packing is improper for a very high pressure, being destroyed by the great heat of the steam. When it is considered, however, that steam at the melting point of lead, at which temperature hemp is not destroyed, possesses an elasticity of nearly eighty atmospheres, the objection loses all force for such pressures as I have used.

perfectly well. This engine was constructed peculiarly for a very great pressure.

I firmly believe that these engines of great pressure would have produced useful results; but I conceived that the experience I had with them, was not based on sufficiently extended practice to determine a manufacturer in adopting them with security. The boilers, although they showed good results in experiment, were not perfected, and other generators for such a great elasticity were not at hand; nor would they, if procurable, have properly exemplified my plans of construction. Moreover, I had good grounds to fear that the public, already prejudiced against the high-pressure system, would oppose it so much the more as the steam used was of a higher elasticity than previously employed. Finally, I considered that to insure a proper care and attention to these engines would be a matter of greater difficulty than with those of a more moderate pressure; and that on this ground the convenience of their use would appear in some measure doubtful; and thereby an objection would be raised against them, which would require more time to remove than I had the opportunity of bestowing.

45. While, therefore, on these grounds I avoided the use of too great a pressure, I retained firmly the principle that the elasticity could not be reduced lower than eight or ten atmospheres, without relinquishing the advantages of the system. For—

(*a.*) The loss of the vacuum would be felt so much the more, the lower the pressure became.

(*b.*) The friction of the piston would be greater, by the use of a larger cylinder for the same power, and

thus a greater prejudicial resistance would be sustained. Notwithstanding the improvements made in this part of the machine, the friction is still so great as to render it advisable not unnecessarily to increase its rubbing surface.

(*c.*) The engines would, at a lower pressure, be larger, less portable, and more expensive.

(*d.*) The principle of expansion could not be made use of to so great an extent, and to such advantage, with steam of a lower pressure. The steam leaving the cylinder would at the end of each stroke retain too little excess of pressure above the atmosphere, and therefore would blow out with too small a velocity, and leave behind an increased resistance to the piston. For example, steam of three atmospheres, expanded to three times its volume, would scarcely balance the atmosphere, and would thus have no tendency to blow out; while steam of two atmospheres similarly expanded, would sink so much under the atmospheric pressure, as to cause a very injurious counter-resistance to the piston from the entering air. Numerous experiments had convinced me of the great advantage of a rapid discharge of the steam from the working cylinder, and I resolved that this discharge must be at least effected with the elasticity of some atmospheres, to take place with proper rapidity, and produce the advantage I have before alluded to. It was also clear to me that the steam, before its departure from the cylinder, ought not to be so much reduced as to render the action too unequal, and thereby to require too large a fly-wheel.

46. In order to take a secure path in the fabrication of high-pressure engines, I conceived I could not do better than follow in the footsteps of Oliver Evans, and adopt as the normal for my future attempts, the pressure he had found to answer in his long and varied practice. Such a pressure had the advantage of allowing me to retain the use of several organs of the old engines, particularly the slide-valve, which presented peculiar advantages in use, and of whose superiority over the conical valve I was convinced by experience. Nevertheless with regard to the boilers of my engines, I strove to proceed upon more secure principles than Oliver Evans had done, and also to reduce the engine itself to a more simple and compendious construction and form, as well as to make its appearance more agreeable to the eye. I reduced the diameter of the boiler as much as I could without detriment to its evaporative power; and, in order to apply the power of the piston to the crank in the most secure and convenient manner and with the least loss, I gave the engine vibrating cylinders, in which last alteration I found it a difficult task to remove all the many defects consequent upon former arrangements of the kind. Fourteen years' experience has proved that I have succeeded in my endeavour to overcome the difficulties of my undertaking: daily have engines built upon these principles been working under my own observation; I have undertaken all necessary experiments and observations to enable me to decide accurately upon their advantages or disadvantages; and have spared no trouble, no exertion, no sacrifice, to improve their construction and make their results more perfect. Under all circumstances I have reduced the consumption of fuel, in comparison with low-

pressure engines, by at least one-third, often one-half, and sometimes still more; a result which points out as satisfactory the pressure I have adopted. The condenser I only make use of under certain circumstances, and give it then an entirely new and peculiar arrangement. I do not recommend any fixed normal form or arrangement of the engine, but, as I have already stated, I would vary the construction according to the circumstances under which the engines are required, and to suit the places where they are to be erected. Nevertheless a certain form may be taken as most preferable, and this I shall fully and particularly describe.

47. Many manufacturers and others skilled in the science of steam are yet of opinion that it is impracticable to work engines to such a high pressure as eight or ten atmospheres. They seem, however, to have forgotten, or not to have known, that such engines are already in use, and have been worked for a length of time with advantage, without requiring those many subsequent alterations and frequent repairs, or incurring the great wear and tear, that have been brought as objections against them. At the present time a great number of such engines are at work in America; in manufactories, in locomotives, and in steam vessels, particularly those upon the Mississippi and the Ohio. If any one with these facts before him still remain incredulous, let him come to me and examine my engines. He will see the simplicity, the steadiness, and the safety of their construction;—their smooth, noiseless, equable, and powerful motion;—and he may satisfy himself of the great amount of the work they are doing. He may

learn that their repairs only affect such parts as are common to all kinds of steam engines;—and that the attention and management requisite for them involve less application, trouble, and exertion, than engines of low pressure. His own observation will convince him that no greater quantity or intensity of firing is necessary for them, and that consequently their boilers are not more liable to deterioration.

48. In order to render the following portion of my work more clear and perspicuous, I shall treat separately of the several more important parts of the engine. Under each head I shall give introductory notices of the labours of previous inventors and improvers of the several parts; of the principles upon which they proceeded; of their errors; of the difficulties in the way of attaining perfection; of the requisites for a right treatment of the subject; and of the deductions I have drawn from my own experience, upon the best means of removing the difficulties and wants in the way. These will serve to introduce the details of the various improvements I have made.

THE BOILER.

49. The boiler involves more difficulty in its treatment than any other organ of the steam engine, particularly when used for high pressure. We have proof enough of this in the fact that no boilers exist which satisfy all the conditions required from them. That I do not here exaggerate, will be allowed by every one who has studied the history of the steam engine, or who has himself devoted his attention to its construction or use.

I have already entered upon the subject of the great defects of the old capacious boilers, and have shown that such apparatus, especially when they are of an angular, prismatic, or indeed any but a cylindrical form,—or even then if not made of wrought metal,—become the peculiar seat of danger in high-pressure engines. I have shown how all sorts of safety apparatus, as well for preventing too great a pressure, as for avoiding other sources of danger, are but uncertain in their operation, and not to be depended on while the objectionable form and size of the boiler itself remain; since so many fearful examples have shown that they are ineffectual in excluding danger, and are still more incapable of removing or mitigating it when it does arise.

50. And yet is this old monstrous form still used with great confidence; yet is it adopted by the great majority of engineers, and looked upon as the most suitable for the efficient generation of steam. All the frightful consequences of the explosions of vessels of this kind have failed in convincing those who employ them of their error; they have still followed the ancient track, and instead of striking at the root of the evil, have contented themselves with trusting, as their fathers did, to the superficial and imperfect safety arrangements so often relied on in vain. The many prizes and rewards offered by academies and scientific societies for the improvement of safety apparatus, show plainly how the true great principle of improvement has been neglected, and the only secure method of avoiding danger overlooked. This great principle, this sure method, is, SO TO CONSTRUCT THE BOILER THAT ITS EXPLOSION MAY NOT

BE DANGEROUS.[2] In all my researches and endeavours to improve the high-pressure boiler I have steadily kept this principle in view.

51. It is only lately that this condition has been somewhat approximated to by the invention and application of tubular boilers; but it would seem that these have been suggested rather by the necessity of providing, for many technical purposes, and particularly for steam carriages, boilers of less content and weight, than by the desire of removing or lessening danger from explosion. Tubes have that form which is most adapted to resist pressure—viz., the cylindrical. If then they are made of small diameter, of not too great thickness, and of suitable material, they may be made to carry out the before-named principle; *i.e.* they themselves, in case of their bursting, will not cause any dangerous consequences to the neighbouring persons or property.[3] This is amply proved by experience.

Unfortunately, however, there are no tubular boilers which satisfy all conditions required. We often hear the subject spoken of as one of little difficulty, easy of decision, and unencumbered with practical obstacles; but such is the language only of the prejudiced and the inexpe-

[2] "Die Kessel so zu construiren, dass sie selbst bei einer erfolgenden Explosion keine Gefahr verbreiten." More literally, "So to construct the boilers, that they themselves, in case of an explosion ensuing, spread no danger."—Tr.

[3] An instance is on record where the bursting of a connecting-pipe of scarcely 2 inches diameter, in a steamer, scalded to death in three minutes the engine attendant and two stokers, who could not escape from the engine-room in time. It is a great fault in the construction of steam boats, that the engine and boiler-rooms are not separated from each other, and that the access to both is usually inconvenient.

rienced. To arrive at the truth, we must seek it with long-continued perseverance, and bring no small share of physical knowledge to our aid; for the subject is beset with perplexities on every side. It presents at every turn a thousand difficulties, a thousand dangers; and would we avoid a Scylla on the one hand, we find a Charybdis on the other. It becomes a most complex problem to construct a tubular boiler for a large supply of steam, by reason of the difficulty of arranging and connecting the great number of tubes it must contain, into one convenient whole. The modern English locomotive boilers cannot be legitimately called *tubular* boilers, because they fail altogether in the grand distinguishing quality of all such—namely, the small diameter of the generating apparatus. The tubes of these boilers are nothing more than a splitting up or subdivision of the ancient fire-tube of the Trevithick steam carriage boiler. From their great outer diameter, locomotive boilers do not avoid the evil of the old capacious form, and therefore do not diminish the objection to it. They have also a defect in the close proximity of the tubes to each other, whereby the water space between them is rendered too confined, and the heated tubes become liable to be laid bare of water. This circumstance gives the key to the well-known fact, that the tubes become so soon destroyed, or at least require constant repair, and to the mischief occasioned by their expansion, through their connection with the end plates of the cylindrical part of the boiler. It is evident that from the passage upwards of the steam formed among the lower tubes, the upper ones must be most liable to be uncovered with water; while these, being exposed to the hottest part of the fire current, are most likely to receive damage therefrom.

The new boiler of M. Neukranz,[4] which Mr. Penn, of Greenwich, usually adopts for steam vessels, is a better arrangement than that of the locomotives: in this, the tubes above the fire-place run across through the vertical fire channel in the interior of the boiler. These tubes are filled with water, have a greater diameter in proportion to their length, and embouche at both ends into the water space of the boiler. Unfortunately, however, these boilers, and all of similar construction, on account of their great circumference and content, are equally far removed from fulfilling the great object of the tubular system.

52. According to my opinion and experience, a tubular boiler ought to preserve, as much as possible, the tubular form in all its parts; or, at least, the larger portions ought to be cylindrical, and not of too great diameter, or should be so strongly made that the tubes should form the weakest part of the whole boiler. The tubes themselves should be of such diameter, and be constructed of such metal, that in case of their actual bursting, no dangerous explosion may ensue. This, however, is only possible when their thickness is so small, and the metal of such a kind, that bursting takes place by a comparatively small internal pressure, and is followed by only a ripping open of the tube, and not a scattering about of massive fragments. Under all circumstances, however, the tubes must be the sole generating vessels; they alone must receive the action of the fire, and be exposed to its destructive influence. All other and larger vessels, or parts connected with the tubes, should be most carefully protected from not only

[4] 'Gewerbblatt für Sachsen,' No. 49, p. 399.

this but all other dangerous influences, in order that they may remain in their original proved condition of strength.

Only such a tubular boiler as fulfils all these conditions can be called a safe one. In its use there is no further danger from high-pressure steam, and near it its owner may repose undisturbed by a care for the safety of life or property.

53. The requisites in the use of the tubes are the following:—They must be placed in such a position with regard to the furnace, that the flame may act upon them in the most favourable manner, and that the heat may be absorbed as completely as possible.—They must have such a proportion between their length and diameter, that neither the ebullition in them may become too violent, and the water be thereby ejected from them, nor that they be warped or made crooked by the heat.—They must properly convey away all the generated steam, and be regularly supplied with water.—They must be connected with the main part of the boiler in such a manner that in case of a rupture of one of them, the whole content of water and steam cannot suddenly and dangerously discharge itself.—They must lie so deep under the general water level of the boiler (in the receivers or separators) that some considerable sinking of the water may be allowed to take place without leaving any of them empty; and in case the latter effect should occur, such tubes must first be emptied as are least exposed to the heat of the furnace. Lastly, they must be connected with each other in such manner that no destructive expansion may be allowed to take place, and that all may be easily and conveniently cleansed of the earthy matters deposited in them.

The enumeration of such requisite conditions shows us the weight of the difficulties I have before alluded to. I will proceed to set forth these requisites still further.

54. The larger portions of the boiler, or receiving vessels, may themselves consist of tubes of a larger diameter, or may form flat chambers, constructed of a strength to withstand a very high pressure (say 400 to 500 lbs. per square inch); this involves no difficulty.—The diameter of the receivers should not, where it can be avoided, exceed 16 inches, and they should be constructed of plate iron of at least $\frac{3}{8}$ of an inch thick, securely and exactly riveted together into a cylindrical form.—When it is necessary that they should be capacious, their length should be increased and not their diameter beyond that specified, or their number should be greater.—Their covering lids (*schlussdeckel*) may be flat and of cast iron, but of considerable thickness ($1\frac{1}{2}$ to 2 inches), and these must be connected to the cylinders securely, and in such a way that they may be easily taken off when cleaning is required. —They must, under all circumstances, be entirely removed from all strong action of the fire, and must at most be exposed only to such currents as have discharged the greatest portion of their heat against the generating tubes.—In order to preserve them from rust, their internal and external surfaces may be covered with several coats of oil-varnish (*oelfirniss*), and the coating renewed, at least on the inside, every year.—Since these receivers or larger parts of the boiler usually serve as separators, and as means of connection between the generating tubes, they must be perfectly adapted to fulfil these purposes. As separators,

they must efficiently separate the steam from the water, so that none of the latter may penetrate into the working parts of the engine; and to this end the water surface in them must be of sufficient extent.—In order that the water may not rise to a dangerous height in them by violent ebullition in their tubes, their water space must bear a certain proportion to that of the tubes and the other parts of the boiler.—The steam room in them must also be proportioned to the content of the engine cylinder; so that the pressure may not be too much lessened by the discharge into the engine, and a foaming of the water thereby be caused.

55. The doctrine I hold that the tubes should form the weakest part of a tubular boiler, will, doubtless, at first sight appear to many of my readers a paradox, or at least a very hazardous rule, seeing that it is in the most glaring opposition to all former views on the subject, and sets all former theories on one side. But if the reasons I have to give in its favour be duly weighed, I trust it will be justified in the eyes of all discerning men.

When this arrangement is adopted, the place where an explosion becomes possible is confined to those parts whose bursting is unattended by danger, and the rupture will take place before the steam has acquired such an excessive elasticity as to produce any very violent effects. Those who have witnessed the bursting of thin copper tubes will bear me witness that by this arrangement all desirable extent of security may be attained. The tubes become safety-valves, whose functions are perfected when a pressure double or triple the proper one arises in the boiler, and when all other safety apparatus forsake their

duty. Thin copper plates and sacks have heretofore been recommended and used for safety arrangements.

If it is objected that by the weakness of the tubes frequent accidents may occur, and that consequently the working of the machine may be often seriously impeded; I answer that a sufficient pressure to cause an explosion, even of these weakest parts, cannot frequently occur: it can only take place through the carelessness or wilful neglect of the machine attendant; and the ordinary safety apparatus are still at hand as far as they will succeed in preventing mischief. In one of my first engines, after many years' wear, the tubes became so much worn that ruptures were of frequent occurrence; yet these were attended with so little danger, that nothing was thought of them beyond the inconvenience of a few hours' stoppage of the engine for repair; and as I had a larger engine in course of erection, I did not think it worth while to renew the old boiler. If the tubes are so arranged, (as they were in my engine, and ought in all cases to be,) that a ruptured one can be replaced with facility and expedition, the objection I have alluded to loses all its weight. A boiler of this kind will possess thereby a great advantage over the common boiler, inasmuch as the latter, in case of explosion, not only is destructive to life and property, but also puts a stop, for a long period, to the work of the establishment. And to draw a parallel between the two cases, will any one assert that these old boilers, particularly for low-pressure engines, will bear a doubly or triply increased pressure with so little mischief as the rupture of one of my tubes would occasion? Is so sudden and dangerous an evaporation to be apprehended from thin tubes when they may accidentally become red-

hot, and afterwards be suddenly covered with water, as from the thick sides of a large boiler? and would not the thereby suddenly increased pressure be more likely to confine its effects to the tube, connected only by a small opening to the larger parts of the boiler? Is not the drying and overheating of the tubes less likely to occur when the receivers or separators are arranged as I have before indicated? and particularly, is not such an occurrence less to be feared in a steam vessel exposed to the motion of the sea?

Tubes of small thickness have the advantage, that they generate more steam than surfaces of stouter metal; because the heat penetrates them more quickly. They are also not less durable, since the heat is less apt to accumulate and produce those destructive expansions and contractions to which, as I have before shown, thick boiler sides are so liable.

I have already stated that the larger receivers or separators connected with the tubes must not, if they are expected to retain their state of security, be acted upon by the strong heat of the fire, the effect of which must be expended upon the tubes, the least dangerous parts of the whole. One of the greatest difficulties in the construction of effective tubular boilers consists in the proper arrangement of the tubes in the furnace, and of the connections between these and the other portions of the boiler, with a view to the most perfect evaporation, and the most complete facility for the discharge of the steam and the supply of water.

56. The most common error in the construction of tubular boilers, is, that the diameter of the tubes is made

too small, and the length proportionately too great. This produces the following inconveniences.

(*a.*) The tubes present, for their length and breadth, too little surface to the fire; and therefore are required to be greater in number for a certain evaporative power.

(*b.*) Their connection becomes a matter of more difficulty.

(*c.*) They are more liable to be choked up with dirt and deposit, and when they become so, are more difficult to clean.

(*d.*) The discharge of steam from them is more apt to drive out the water and leave them dry, whereby they are exposed to speedy destruction by the fire.

(*e.*) By offering impediment to the free and equal flow of the steam and water, they are liable to become warped or crooked, and otherwise injured by an unequal action of the heat.

All these inconveniences are got rid of by giving the tubes a sufficiently large diameter; such as at least *four inches.* Tubes of this diameter are large enough to represent small boilers, which have a proper proportion of heating surface to their cubic content, and in which the water and steam space is so ample that the vapour may discharge itself without either carrying the water off with it, or at all hindering the proper supply. When tubes of such a diameter are made of suitable thickness of metal, no danger is to be apprehended from their bursting; for their steam and water content is of no considerable magnitude.

The length of such tubes may be *from sixteen to eighteen times their diameter.* To make them longer would render

them liable to the objections I have alluded to, and to other inconveniences I shall hereafter explain.

A very important advantage of such tubes is the facility with which they may be cleaned. For this purpose they must be provided with suitable covers, capable of being removed with facility, to allow of the proper introduction of the cleaning instruments.

The connection of the tubes with the other portions of the boiler must be made secure, and in such a manner as to admit of their being easily renewed when requisite, and to prevent a sudden discharge of the whole contents in case of a rupture. The manner of accomplishing this, I shall show when I come to describe my own boilers.

57. The method of placing the tubes in the furnace so as to obtain the greatest effect of the fire, has been the subject of much difference of opinion; the modern view, however, is, as generally received, that a *vertical* position is the least advantageous. The heated current strikes upon vertical tubes and surfaces too swiftly, and finds too little resistance to enable it to discharge its proper amount of caloric.[5] If this is to be properly absorbed, the current must, in its draught through the furnace, strike as nearly as possible perpendicularly against the objects to be heated, and be so divided by them as to be compelled to vary its course. Many men of science have acknowledged this fact,[6] and experience on all sides corroborates it. How this may be done, I shall hereafter show. Suffice it here

[5] In one of my engines I adopted first the horizontal and afterwards the vertical arrangement; but although the latter had 50 per cent. more surface than the former, it required 50 per cent. more fuel.

[6] *Vide* 'Seguier, Recueil industriel,' 1831, pp. 1, 89, 155.

to say, that horizontal tubes are in this respect the more suitable, as well as possessing all the other qualifications of good evaporating vessels. This position is, in many respects, preferable to either the oblique or the vertical, as my own long experience has amply proved.

So much for the conditions upon which tubular boilers should be constructed: I shall have more opportunity of exemplifying them further on. Meanwhile, I proceed to make some remarks upon tubular boilers in general.

58. Over-ebullition is least to be feared in tubes half filled, since in them the steam space is well separated from the water. There is, however, much difficulty in so arranging the supply of water, that when many tubes are used together, it shall be kept at the same height in all. My experience has shown me that this involves difficulties even in tubes of large diameter, and produces evils which are avoided by a different plan. Half-filled tubes give less evaporation than those entirely full, and therefore require, for the same steam supply, the whole apparatus to be of larger dimensions,—an objection often of great weight. The disadvantageous ebullition above alluded to, to which full tubes are more liable, is but little to be feared if the tubes are constructed of proper dimensions, and are laid in the furnace slightly on the incline, that the steam may have liberty to escape freely by its levity, as it becomes formed.

59. Many inventors of tubular boilers have recommended a long coil of tube of small diameter running in many windings through the furnace; receiving the water at its lower end, and discharging the steam at its upper. This

plan is objectionable, not only on account of the great difficulty or almost impossibility of cleaning the tube, but because variations in the intensity of the fire, or in the regularity of the feed, will inevitably produce a drying of some portion of the tube, and its consequent injury by the fire.

60. Tubular boilers are seldom used for low-pressure steam. They are more particularly adapted for high-pressure, in that the latter acquires a much smaller volume, and is generated with a proportionately much less violent ebullition. The higher the pressure, the smaller are the bubbles of vapour, and the easier their transmission through the water. Hence a tubular boiler that might, under a low pressure, fail from the drying of its tubes, answers perfectly well when the pressure under which it worked is increased. From this it follows that the pressure has a considerable influence not only over the ratio between the cubic contents of the tubes and the receivers and separators, but also upon the diameter of the tubes themselves, and the size of the openings by which they are connected.

61. When, after a fire is lighted under a high-pressure boiler, the water first begins to boil, the steam is formed under a low but constantly increasing pressure; and under such circumstances, the *volume* of the steam produced, and the consequent ebullition, are much greater than when the full pressure is attained. From the consideration of this we gather the rule, that caution should be employed in firing while getting up the steam, especially when the tubes are small, or the proportion between them and the

receivers unfavourable. If the fire is at first made too strong, the water will be driven out of the lower tubes, as will be evidenced by the rising and unsteadiness of the water level in the separators. When, however, the pressure has attained its proper height, the fire may be increased without fear, and the water will then resume its steady and accustomed level.

62. I have found that in the low-pressure boiler, the production of a cubic foot of steam per second requires a water surface of from 5 to 6 square feet, in order that it may be produced freely and without too violent ebullition: this supposes the steam to be evolved equally from every part of the surface. Here, therefore, is a *datum* for the proportions of the receivers of such tubular boilers as work with filled tubes; and we are compelled by this rule to give their water surface the greatest possible extent. Hence all upright receivers or separators whose length much exceeds their diameter, are objectionable, and on this ground many modern improvements on tubular boilers have failed. In steam vessels, however, the rule must be somewhat relaxed, as we have another element to take into consideration—namely, the motion of the ship, which has more influence on the level of the water in horizontal than in vertical separators.[7]

63. The great defect of almost all tubular boilers is the difficulty of cleaning them. This objection applies to

[7] The Author here proceeds to comment on the boilers of Gurney, Gillman, Ogle and Summers, Maceroni, Squire, Dance, Hancock, and others. I have not thought it necessary to insert these remarks, as the boilers alluded to are so little used in England.—Tr.

most of those boilers used for steam carriages on common roads, and all such inevitably contain the germ of their own destruction.

This most important requirement is always difficult to be accomplished in tubular boilers, and especially in those that contain a large heating surface with a small cubical content, since it is generally impossible to open them fully in order to gain convenient access to the interior surfaces. It has been therefore often attempted to effect the cleansing by chemical instead of mechanical means; and the attempt was at first taken up with great enthusiasm, owing to the satisfactory results which it appeared to afford. But it has been a delusion. I myself have given these chemical means a fair trial, and have found them not only expensive, but untrustworthy, especially the much praised application of muriatic acid (*salzsaüre*). I have found that the boiler-stone becomes thereby somewhat loosened, but never dissolved;[8] and I have always had afterwards to scrape off and remove it. If the diluted acid is allowed to work longer to effect the more perfect solution, danger is incurred of the metal becoming corroded, especially in those spots where no deposit may lie: this danger is most to be apprehended with iron boilers. It should be considered that the boiler's deposit consists not alone of lime, but of many other salts and substances, such as gypsum, &c., which resist the action of muriatic acid.

64. But little better success has attended the labours of those who have endeavoured, by means partly chemical,

[8] Den Kesselstein etwas erweicht, aber nie ganz aufgelöset.

partly mechanical, to *prevent the accumulation* of deposit in the boiler, and thus to render cleaning operations unnecessary.

One of the oldest of these means is the introduction of *potatoes* into the water. Upon the quantity necessary different views are entertained.[9] The action of this preventive is explained upon the supposition that the potatoes are converted by the boiling water into a slimy fluid (*brei*) which retains the precipitates finely suspended (as gum-arabic suspends the pigments in water colours), and allows them to be removed with it; it being a necessary condition that the water be occasionally drawn off. I have used potatoes under my own observation for eight years in all imaginable ways; sometimes in their natural state, sometimes peeled, and sometimes previously mashed into pulp; but I yet remain doubtful whether their use is attended with advantage or not. I have frequently found the deposit adhere as firmly with as without them, particularly in the connection tubes, where the ebullition has been considerable. It is so far certain, that where pure and soft feed water is at hand, their use is rather prejudicial than advantageous, as they tend to cause *priming*, and by passing into the engine render the hemp packings stiff and inelastic; besides which, they tend, especially when used whole and unpeeled, to block up narrow and confined parts of the boiler and its connections. In newly riveted vessels they may at first be useful in stopping small leaks in the joints, by gradually depositing and hardening therein. Also where the water is very hard or acidulated, potatoes may be of use in diminishing the destructive chemical

[9] According to Payen $\frac{2}{100}$ of the weight of water are introduced into the boiler.

action upon the metal. In these cases, or any others where advantage is thought to accrue from the plan, the potatoes should be peeled, in preference to using them in their natural state.

It has been asserted that the use of potatoes would loosen boiler-stone already hardened upon the plates; but though I have taken great pains to prove the assertion by experiment, I have never succeeded. I at first imagined that the loose state in which I found the deposit in my boilers was owing to the application of this preventive; but, to my great satisfaction, I soon discovered that the result was produced as well without as with it, and since then I have never used potatoes where I could get soft feed water.

65. *Charcoal powder* has been recommended, but this, often renewed, would be expensive. *Clay* is also among the remedial substances named; but I cannot understand how the introduction of one earthy substance can prevent the deposit of another. Another method proposed to prevent the adherence of deposit is to cover the internal surface of the boiler with a coating of *black lead and tallow.* This, or indeed any oleaginous matter introduced into the boiler, is supposed to prevent the firm adherence of the deposit to its sides. *Grains of metal,* or *small balls,* are stated to act mechanically in keeping up a constant motion, and preventing the formation of hard deposit. *Troughs, separators,* and apparatus of various kinds, have also been introduced into boilers. And lately a patent has been obtained for an application of *vegetable matters,* such as dye-woods, turf, leaves of trees, &c., &c., for the same end. It has been also proposed to introduce certain *salts* in the feed water, whose acids will form easily soluble

compounds with the earthy bases of the deposits, or whose presence will otherwise prevent incrustation.[10]

66. Seldom, however, are any such preventives necessary for high-pressure engines. If the feed water is not very hard, a firmly incrusted deposit is but rarely found in their boilers. The earthy concretions generally collect in loose layers upon the bottom, or against the ends of the tubes: the layers consist usually of gravel-like masses, small and large pieces commingled, and they may be easily removed with a scraper. When the tubes are small, this must be frequently done; otherwise stoppages may be produced in the water passages. For this purpose I have so constructed my boilers that they may be most conveniently opened and cleaned from time to time. If it is wished still more to prevent the accumulation of this loose deposit, I recommend half a bucket of water to be drawn off occasionally, during the working of the boiler, when the water is at its highest level. This plan has the double advantage, that not only a great mass of the deposit in formation is blown off, but the water is prevented from attaining that state of saturation in which the hard precipitation begins. Where muddy or slimy, or salt water is used, this frequent blowing off is especially necessary.[11] In my boilers the draw-off opening is situated as low as possible, and I find all the impurities and salts which collect at the bottom of the boiler are thereby easily removed.

[10] I have abbreviated this paragraph, since the Author's remarks upon these methods contain no information of importance. References to all his authorities are given in the original.—Tr.

[11] Messrs. Maudslay and Field's brine pumps act on this principle.

67. Although the amount of evaporation depends on the extent of the heating surface of the boiler, through which the heat of the fire is applied to the water; and although on this account a vessel with a small *water content* may be made to evaporate as great a quantity of water as one in which the same element is large, provided the amount of heating surface is the same in both;—yet it is a great mistake to reduce the cubic content of the vessel to the extent many inventors have done, imagining such an alteration to be advantageous. A small water content has indeed the good property of enabling the steam to be raised at first with a reduced loss of time and fuel; but it has a more important disadvantage in making the action of the boiler too irregular, and too much dependent on changes in the amount of the load on the engine, or in the intensity of the fire; besides rendering a greater degree of care and attention necessary in the management. I will explain this more at length.

When a boiler is first set in action, the water gradually rises to the boiling point, and then begins to evolve steam of atmospheric pressure. The firing being continued, the vapour, unable to escape, begins to collect in the steam chamber, acquiring constantly a greater pressure and density; and the water assumes an increase of temperature corresponding to the density of the steam; for otherwise the evaporating process could not continue. The converse of this takes place when the pressure and temperature of the steam are reduced. I have before remarked that when the pressure upon the water in the boiler is lowered, a portion of the free caloric in the water will be employed to form steam; and this takes place whenever, by either an increased consumption of steam in the

engine, or a reduced firing, the pressure in the boiler is lessened: evaporation will then continue till the temperature of the water assumes that corresponding with the pressure of the steam. Now the evaporation thus produced will be the more rapid, and last the longer, the greater the quantity of water in the boiler; and this water content thus tends to act as a provision against a too sudden diminution of pressure by a relaxed firing. On the other hand, the same provision also prevents too sudden an increase of pressure when the fire is increased; since steam of a higher elasticity cannot be generated before the whole volume of water has acquired the corresponding temperature; and this requires a longer time in proportion as the volume is greater. Thus boilers with a large water content work, for these reasons, much more regularly, even with a less regular firing; and the greater the volume, the greater the regularity. We must not, however, be led, on this account, always to give the greatest content possible, but must, as in so many other matters, adopt the golden mean between the extremes of irregularity on the one hand, and unnecessary waste of time, fuel, and material on the other.

This mean is better arrived at by experience than by complicated calculations. In my own practice I have adopted the rule, founded on my own experiment and observation, that for every *eight* or *ten square feet* of heating surface, there should be allowed *one cubic foot* of water content. This rule is to be observed even in tubular boilers with small tubes, if they are provided with receivers or separators. How little this practice has been followed in the majority of tubular boilers, must be too obvious to need demonstration.

68. Of equal importance with the consideration of the water content of a boiler, is that of its *steam space.* It is wonderful to observe how contradictory are the rules laid down for guidance on this point. But since contradictory rules are useless, I pass them entirely over, and turn again to my own experience. High-pressure engines have on this head a great advantage over low-pressure, especially if they are worked expansively. They have a much less volume of cylinder to be filled, and since the steam space must bear a direct proportion to this, a less space is required for a given power as the pressure is greater and the steam used more expansively.

The following considerations should lead us to a just determination of the proportion between the two.

(*a.*) The steam space should be so large, that in the discharge from the boiler to the cylinder, the pressure in the former should not fall in any considerable degree, and the mercury in the manometer steam gauge should not exhibit any considerable fluctuation. I find this condition is fulfilled under all circumstances in my engines when the cubic content of the steam space is at a minimum *twenty* times as great as the space to be filled with steam in the cylinder. If it can be made greater, consistently with the other arrangements of the boiler, so much the better.

(*b.*) The steam space should be capacious enough to prevent the danger of *priming.* The water in the boiler has always a tendency to rise immediately under the steam opening when the discharge takes place and the pressure is diminished; but I have found that the proportion of space I have above mentioned is sufficient to prevent this, especially if due care is taken

that the steam opening is sufficiently elevated above the water level, and is situate over that portion of the water where the least ebullition is likely to take place; for instance, as far as possible removed from the *débouchements* of the tubes.

How few of the modern tubular boilers conform to these requirements![12]

69. The present will be the most convenient place for introducing an investigation of the question,—what amount of heated surface (*feuerberührungsfläche*) is necessary for a certain power?

On no point connected with steam engines has there been more error than on this. It is most remarkable to see the strange views which have been held respecting the sources of the evaporative power of the boiler, and, among these, one of the strangest is the idea that this power depends upon the water content or the water surface, irrespective of the amount of surface exposed to the fire. Rules based on these erroneous principles will be found in many English works on the steam engine. But the dimensions and proportions of high-pressure boilers seem to have been altogether involved in confusion. It has been imagined that because the engines themselves, or their cylinders, have been of less magnitude than for low-pressure engines of equal power, therefore the size of the boilers might also be proportionately diminished, and a less amount of heating surface might suffice. Thus we often find only about *five* square feet per horse-power

[12] The Author here, in the original, is very severe, and not without reason, upon the many fallacies published in England, some of them in an authoritative dress, upon this point.—Tr.

allowed in such engines, and sometimes indeed less than this. Now although it is quite true that a high-pressure engine does require a less volume of steam in proportion to its effect, yet it by no means follows that the heating surface is to sustain the same proportionate diminution. If it *is* so diminished, no wonder that it is found requisite to increase immoderately the size of the furnace, and thus to introduce the most monstrous disproportion between this and the dimensions of the boiler. I have frequently seen one foot of fire allowed to four of heating surface; and have never met with an instance where a correct proportion was maintained. Errors of this kind are remedied by forcing the intensity of the fire, but this always involves a greater expenditure of fuel, and an increased wear and tear of the boiler and furnace. Is it possible that fuel can be economized under such circumstances? Is it not evident that the boiler and furnace-bars must under such a use be sooner destroyed than in low-pressure engines? And are not these errors thereby the cause of bringing the high-pressure system into unmerited obloquy?

And yet is the matter so simple, its treatment so obvious. In order that a certain quantity of heat may be taken up, a certain amount of surface must be exposed; and this must be so much the greater, the *less* the difference between the temperatures of the boiler and the fire current. But this difference is obviously less in the high-pressure than in the low-pressure boiler, and therefore the former would appear to require a *larger* surface for a given power than the latter.[13] Since, however, according to experiment, an equal heating surface,

[13] *Watt* allowed for his low-pressure engines 8 square feet to evaporate 1 cubic foot of water in one hour, producing one horse-power. But by far

acted upon by an equal fire, will produce an equal amount of evaporation at all pressures, we obtain a rule that the fire surface should at least be equal at all pressures, for an equal quantity of water evaporated.

When the surface is so arranged that the greatest possible amount of heat is abstracted by the boiler, this should be testified by the temperature of the current which escapes into the chimney being reduced to nearly that of the boiler; and the more the former exceeds the latter, so much the farther are the arrangements from perfection, and the greater the loss of heat and fuel.[14]

70. The following are the rules I have been led to by my experience and researches:

(*a.*) High-pressure boilers should have much greater surface exposed to the heated current than hitherto generally given them. For high as well as low pressures the allowance should be—

For small engines of from *one* to *six* horse-power, 14 square feet per horse-power;

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the majority of low-pressure engines require $1\frac{1}{2}$ to 2 cubic feet, and therefore Watt's rule agrees tolerably well with the one I have given further on. This great man followed always the path of experience,—the only direct road to knowledge; his active life was spent not in calculations but in the work of his laboratory. WATT appeared as a dazzling meteor whose brilliant ray illumined the darkness of his age. But his light is extinguished, and since his time its place has only been supplied by the dim tapers of his followers and imitators, whose dulness seems rather to recall the ancient darkness than to perpetuate or renew the splendour which his great spirit threw upon the world.

[We beg to take an exception here in favour of the Cornish men.—TR.]

[14] It is possible to make the smoke current pass off into the chimney at a temperature even lower than that of the steam in the boiler, and I believe this is common in Cornwall. See 'Treatise on the Cornish Engine,' Art. 130. —TR.

From *six* to *twenty-five* horse-power, 12 feet per horse-power; and

From *twenty-five upwards,* 10 feet per horse-power.

With these proportions a less surface of *fire-grate* than usual will suffice. I allow

In engines *under twenty-five* horse-power, 1 square foot of grate for 14 feet of heated surface;

In larger engines, 1 square foot to 16.

Under these proportions I find that no more heat escapes into the chimney than is necessary to produce a moderate draught; the fuel is economized; and undue wear and tear prevented.

(*b.*) The surfaces should be so placed in the furnace that the heated currents may be made, as much as possible, to impinge perpendicularly upon them. The heat is by this plan most quickly and completely absorbed, but it is not always free from difficulty in its application. The most advantageous arrangement is when the current strikes upwards in a zigzag direction among the tubes of a tubular boiler; so that after it has passed through the narrow spaces between the lowest range of tubes, it impinges upon the tubes themselves in the second range, placed immediately over the spaces in the former; and so on among the whole. The current is thus divided into thin sheets, whose heat is much more readily abstracted than in the large flues of the common boiler, where only the external part of the current is brought into immediate contact with the surfaces to be heated. The plan I have here recommended will be fully illustrated in the second form of boiler I shall hereafter more minutely describe.

71. Many improvers of boilers have tried means of increasing the evaporative power without giving a greater extent of heating surface; by introducing into the boiler pebbles, shavings, saw-dust, brass wire, shot, &c. I have found some of these actually increase the evaporation, in a degree generally depending on their conducting power. The heat appears to pass easily from the heated surfaces of the boiler to the loose metallic bodies, and to be distributed thus over an increased surface to the water.[15]

72. I have now another question to consider which is of the greatest importance with high-pressure boilers—namely, how great their diameter should be. On this point also there is much error existing. We constantly find a diameter of 5 or 6 feet given to vessels intended to bear a pressure of 4 or 5 atmospheres; indeed a less diameter than 3 or 4 feet we seldom meet with; under 2 feet, never.

Many rules exist for calculating the diameter and thickness of metal of boilers of various construction and material;[16] but these do not touch the principal question,—

[15] Mr. Williams, of Liverpool, has lately taken out a patent for a new method of increasing the transmission of heat to vessels containing water or other fluids, by inserting metallic pegs or conductors through the portions of the vessel acted on by the fire; thus increasing the surface both inwardly and outwardly. I had at an earlier date attempted something similar, but found that the oxydation on the outside, and the deposit on the inside, frustrated all my attempts.

[This invention, embodied however in a more comprehensive claim, forms the subject of a patent taken out about eight or ten years ago by Mr. John Sylvester, of London.—Tr.]

[16] One of the best treatises on this subject is that by Professor Johnson, of the Franklin Institute. It may be found in the 'Repertory of Patent Inventions,' January, 1832, p. 44. The formulæ seem, however, to me imperfect,

how far we may increase the diameter consistently with safety. Nor indeed are such formulæ necessary if we limit our boilers to a certain size, or confine them to a given diameter in all cases. Further, such rules are to a certain extent mischievous, in that many manufacturers may trust too implicitly to them, and fall into a dangerous confidence which may subsequently prove entirely misplaced. If we determine to retain the same size of vessel for all cases, the dimensions and thickness will be soon found by experience, without any great amount of trouble.

According to my views, a satisfactory degree of safety may be obtained in two ways. Either

(*a*.) By making the diameter as small and the thickness as *great* as possible; whereby the vessel is enabled to withstand a pressure very much greater than usual, and to remain secure even after considerable wear: or,

(*b*.) By giving the vessel a small diameter, and only a *small* thickess of metal; such a thickness as will not allow the pressure to increase to too great a degree, and will in case of rupture spread the least possible danger.

Experience alone can lead to a proper decision on this point. I shall hereafter describe two kinds of high-pressure boilers, both of which I have used with perfect success, and whose perfect safety has been practically proved. In the first, used for small engines only, I do not allow the diameter of the tubes (both are tubular boilers) to exceed 12 inches. It consists of two ranges of tubes, the upper 12 inches and the lower 8 inches diameter, and I find a thickness of ¼ inch amply strong

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inasmuch as they are calculated by the strength of *bar* iron, whereas the *plate* iron of boilers is generally so much inferior in cohesive strength.

enough, whether the material be iron or copper: the latter being a weaker metal, would theoretically require a greater thickness than iron, but I find this, or even $\frac{3}{16}$ of an inch enough. I have proved that such plate will tear open without danger. In three instances, copper vessels of this construction have burst without doing the least damage; and in one of these cases I was standing opposite the fire-door and looking into the furnace at the time the accident occurred, but I did not receive the slightest injury.[17] Oliver Evans made the diameter of his cylindrical boilers 2 feet, and their thickness 2 lines: they seldom produced any mischief, but simply opened in rents which caused no damage. It would be well worth investigation whether, even for boilers of large diameter, thin metal is not less dangerous than thick. There appears every probability that the former would produce nothing but a harmless rent, where the latter would cause a most destructive explosion, scattering fragments in every direc-

[17] This was with an engine of ten horse-power, erected by me at a paper manufactory at Bützow. I was called in by the foreman, on account of the engine having begun to slacken its speed. I found nothing the matter with the engine itself, but turned to the boiler, and immediately perceived that the float had considerably sunk. I quickly opened the fire-door, to check the combustion; and as I looked into the furnace to examine the intensity of the fire, the explosion took place. It was accompanied with a dull report in the furnace. A portion of the fuel and some steam and water crackled (*prasselten*) around me, but without hurting me; and after an examination I found a rent 2 feet long, and in one place 6 inches wide, in one of the lower tubes. Notwithstanding this explosion, not a stone of the furnace was displaced, not even in the thin division wall between the tubes.

Both the other explosions I have named were equally harmless. One was in a large, the other in a small tube. Both were caused by a deficiency of water, and in both instances the fire-door was shut. In the first case a few stones were displaced, but with so little force that they were not removed a couple of paces from their original position.

tion. For copper vessels, I would adopt the thin metal without hesitation.

In my second form of boiler, I have adopted thin copper tubes which alone are exposed to the action of the fire, upon the principle already stated; viz., that they may form the weakest part of the whole boiler; and therefore, if a rupture takes place, it can only happen in the tubes, from which, on account of the tenacity of their material and their small diameter, no danger can arise. It must not be forgotten that the thinner the tubes are made, the more quickly they transmit the heat from the fire to the water they contain.[18]

73. The question, what metal is most suitable for the construction of boilers, is almost answered already. Copper is in every respect the best material, not only on account of its extraordinary tenacity, which prevents its flying in pieces, but also because it is a better conductor of heat than iron. It is dear, costing nearly five times as much as iron; but when old it may be disposed of advantageously, and will generally realize at least half its original price.

When fuel is used which evolves acids of sulphur in the combustion, as is the case with many kinds of turf and pit coal, copper is more affected than iron: the former is, however, less susceptible of injury from rust, and upon the whole may be pronounced the more durable of the two. For steam navigation copper is much to be preferred, as it is less injured by the action of sea water. An iron boiler under such circumstances seldom lasts

[18] Thick metal, however, tends, by storing up heat, to *regulate* the action of irregular firing, like a large water content. See Art. 67.

longer than four years, while a copper one will endure seven, without requiring removal from the vessel for any extensive repair.[19] With fresh water an iron boiler will last usually seven years. Iron is, as already remarked, more cohesive and firm (*haltbar und fest*) than copper, but does not retain its toughness so long; it flies in pieces, and does much mischief on explosion.

Other metals than these two are seldom used for boilers, except for some detached apparatus; such as gun-metal (*messing*) for valves, cocks, floats, &c. This metal has also of late been used for the small tubes of the Stephenson locomotive engine, as more durable than copper. It also expands more equably with the iron of the boiler, and is therefore less likely to produce derangement of the connections.

Copper tubes have the great advantage that they may be joined with hard solder (*schlageloth*). Joints so made, if properly done, are not only much more likely to be tight than riveted ones, but are usually firmer and more tenacious than the substance of the metal itself. In cases where my copper boilers burst I have always found the soldered parts undamaged, whereas iron boilers always give way at the riveted joints, these being the weakest parts of the whole. This is evident, since the rivet-holes remove a large part of the metal; and the closer the rivets are placed, the weaker the boiler becomes. Many boiler-makers adopt a double row of rivets, placing them wider apart, and the rivets in one row opposite the spaces in another. Whether this plan is attended with advantage I cannot say, not having the warrant of experience

19 *Vide* the evidence of Mr. Joshua Field, on the question of steam navigation to India.—'Mechanic's Magazine,' No. 620, p. 249.

for decision. Of my boilers, only iron ones of the first described kind are riveted; these are done in the simple manner, but with the greatest care.

It has been asserted that copper, when used in combination with iron in the construction of steam boilers, induces a galvanic action destructive in some degree to both metals, but particularly to the iron.[20] I have, however, constantly used both in combination in my boilers, but have not found this effect to ensue. It is indeed very difficult to construct copper boilers without using some iron in conjunction with them, particularly for bolts and fastenings, for which copper or brass would be too weak to make the joints perfect and durable. But when has it ever been found that in the engines themselves, where several metals, such as iron, copper, brass, tin, and lead, have been used together, that any such destructive galvanic action has ensued? And yet in many of these cases the parts have been equally exposed to the combined action of heat and moisture.[21]

74. I now come to treat of the *appendages to the boiler*. And first of

THE FEEDING APPARATUS.

In modern times the opinion has considerably gained ground, that explosions of boilers seldom occur in consequence of a gradual increase of elasticity of the steam. On the contrary, unequivocal proofs have been presented

[20] Janvier on Steam Vessels and their Engines.

[21] The Author after this inserts a short passage on *boilers of injection:* this I have not thought it necessary to copy. Such boilers are scarcely known among English engineers.—Tr.

in many cases that the accident has been preceded by a diminution instead of an increase of elasticity. Now in the great majority by far of such instances, it has been found that this was accompanied by a sinking of the water level below its proper line. I have in a former part of my work treated of this occurrence as one of the probable causes of explosion; but without reference to this, the undoubted fact that such a sinking has frequently accompanied accidents of this nature, is sufficient to induce the necessity of great attention being paid to the perfection, in principle, manufacture, and action, of the apparatus for the supply of water.

Unfortunately, however, it must be admitted that the complaints we so commonly hear of the untrustworthiness of apparatus of this kind, especially in high-pressure engines, are not without ground; for many of the machines ordinarily constructed for supplying boilers are very imperfect, and in their use entail constant danger of failure. Much ingenuity has been expended on this object,[22] but yet with little success. The improvement of the feeding apparatus is attended with much more difficulty than appears at first sight; but it seems to me that this difficulty is much enhanced when attempts are made to get rid of the old apparatus, the *pump*, and to substitute new contrivances in its room; for all such, as experience has shown, involve more defects in themselves that are inherent in the machine they are intended to supersede.

75. Almost all substitutes for the feed-pump depend on

[22] Here the Author refers to the descriptions of apparatus by Hall, Franklin, Jeaks, Potter, Taylor, Pequeur and Hallette, William, Baddeley, White, Fox, Seguier, Pott, Taylor and Davis, Whitelaw, and others.

one principle, the only variations being in the mode of its application. A chamber is put in communication alternately with a water reservoir and with the steam boiler. From the former it fills itself with water, and when this communication is interrupted and that with the boiler opened, the contents are allowed to flow into the boiler. The entrance of the water into the chamber is effected partly by its gravity and partly by the condensation of the steam which finds its way into the chamber from the boiler when the water is discharged. Many of these apparatus have been so arranged that they would only fill the boiler to a certain height, namely, the prescribed water line, the action of the apparatus ceasing spontaneously when this level is attained.

The opening and closing of the communications to the chamber are usually effected by means of cocks. In many instances, the whole depends upon a single one, which contains the chamber in itself, and by its motion presents its opening alternately to the passage from the water vessel and to that from the boiler.

All these apparatus have, however, been attended with but little success, and as often as new improvers have attempted to revive them, so often have they again fallen into oblivion. One principal cause of this failure is, that the cocks and rubbing apparatus employed to change the motion have soon become deranged by the deposit from the water, and the variations of temperature to which they have been exposed. This derangement would of course be greater in proportion as the rubbing surface was more extensive; and on this account those machines which enclosed the chamber within themselves have usually most disappointed the hopes of their patrons.

76. The force-pump hitherto commonly in use has in every respect the advantage over all these contrivances, if we leave out of view the expenditure of power, sometimes not inconsiderable, necessary to work it. When, however, a proper construction is adopted, which will enable the action of the pump to be relied on, its simplicity and convenience will always much outweigh any objection that can be brought against it on the ground of its consumption of power. But hitherto most of these force-pumps have been far from perfect. Among the defects most common, I may name especially a faulty construction of the plunger and its stuffing-boxes, or of the piston, cylinder, valves, &c., &c. For example, the plunger may be badly turned and not exactly cylindrical, and the stuffing-boxes too large and badly packed; or the cylinder may be carelessly and unequally bored, and the piston imperfectly leathered,—so that air will enter and destroy the efficiency and regularity of the action. Or the openings may be so situated that air which has once entered cannot be again expelled. Or the valves may be faulty in many ways:—they may not be made of the proper metal (gun-metal, *messing*), but of some other which will soon oxydate;—they may be too heavy, so as not to open with sufficient ease;—they may be imperfectly and improperly fitted to their seats;—they may give too little opening;—they may be badly guided, and be liable to fall improperly back upon their seats;—their stalks may be too short, or may shake in their guides, or may be liable to wedge and stick fast, or to be easily fixed by impurities in the water;—their surfaces of contact may be too broad, or too narrow, or too conical;—they may be unprovided with proper arrangements for withdrawing them for repair or cleaning

when they become leaky or foul; for these pumps require a constant watchfulness, and all their parts should be easy and convenient of access when derangement is observed. If these defects exist, it may be safely asserted that the pumps will often fail in their duty, and will require a great expenditure of time and trouble to put them in order again, thereby causing the most inconvenient and dangerous interruptions in the action of the engine to which they are attached.

To the before-named imperfections we may add others; such as an improper height of the suction-pipe, preventing the entrance of the water in sufficient quantity under the plunger, especially when warm water is used for the feed, by which vapour may be generated and the vacuum necessary for the action of the pump destroyed. Or the strainer may be too wide in the mesh, whereby impurities may find their way inside;—or too narrow, so as to be soon stopped up;—or it may be improperly placed, so that the impurities of the water may collect against it. Or the air-cock, which is often attached to the pump to discharge any air that may have entered, (and which by the before-mentioned faulty position of the openings may not be able to find its way out otherwise,) may be productive of more evil than good, by admitting air instead of discharging it. These cocks, so inconvenient to manage, ought never to be wanted, if the pump is properly made.

Again, apart from defects in the construction of the pump, many other causes may arise to obstruct or interrupt its free action: such as faults of the attendant, in not bestowing proper care on the state of the apparatus, or in neglecting to purify the water from straws, chips, sand, or the other endless varieties of dirt which may be

liable to accumulate therein. Or the locality may be unfavourable to cleanliness, as in cement-works, gas-works, grinderies, saw-mills, &c. Or the water itself may be naturally bad, containing impurities of a mechanical or chemical nature that may have a deteriorating effect upon the working of the pump or the state of repair of its various parts. Against such evils as these nothing but care and continual watchfulness can provide a remedy.

THE SAFETY APPARATUS.

77. Safety-valves are also often of very defective construction. One of the principal faults is the face of contact (*dichtungsfläche*) being made too broad. This has the great disadvantage, that when the valve is opened, the steam, penetrating between the conical faces of the valve and its seat, acts upon a considerably larger surface than when closed; and as a consequence the valve, once opened, will not shut again till the pressure is diminished below the elasticity which opened it, and which is supposed to be the normal pressure. I have frequently remarked that under such circumstances the elasticity has been diminished upwards of two atmospheres before the valve closed: the use of a good manometer will show the fact.

Another fault frequently found in the construction of safety-valves is making them of iron. Such valves rust easily, and stick fast, as I have often witnessed in England.[23] Gun-metal valves are not indeed entirely free from this danger, but are much less liable to it than iron ones. It is to be recommended that all valves should occasionally be lifted from their seats, and their state examined. This

[23] *Vide* 'Mechanic's Magazine,' No. 862.

precaution would render the use of two valves to one boiler unnecessary; an arrangement often recommended, but seldom found to be of much practical utility; for the reason that the one which is usually locked up is neglected, and soon becomes useless.[24]

78. The cause of the sticking of safety-valves often appears enveloped in mystery. Frequently this accident occurs in consequence of the presence of some substances in the water, which, being driven through the valve, become adhesive on drying. I have very often observed sticking take place immediately after a too wide opening of the valve with the hand, whereby generally some water has been discharged with the steam; and this has particularly happened when the water in the boiler has contained potatoes, clay, or mud. Many wonderful and incredible stories have been related in reference to the sticking of valves, and much more wonderful and incredible hypotheses have been invented to explain them; but in most cases, were the exact circumstances more accurately known, they would be found to be much less extraordinary, and capable of much more simple explanation than has been supposed.

The invention of the safety-valve was one of the most important of any connected with the steam engine. It has been claimed by the English, but is generally attributed to Papin. Whether he was actually the inventor does not appear to be made out with exactitude; but it cannot be controverted that he was the first who made use of high-pressure steam, and that the first mention of the safety-valve is made among the records of the inventions he left behind.[25]

[24] *Vide* 'Cornish Engine,' Art. 143.

[25] I have omitted a disrespectful sneer at English appropriation of inven-

79. The conical safety-valve with lever and weight appears to me the best suited for the high-pressure engine, especially if it is so arranged that the weight may be fastened in its place by a set-screw. The use of a spring, as adopted generally on locomotives, does not seem advisable. If it is of steel, it easily rusts and fails in its action; and if of brass, is liable in some measure to the same defect. Both lose in elastic power by heat, and cannot then be depended upon.

It has been objected to conical valves that they do not long remain steam-tight, but require very frequently to be re-turned and ground; but I have not observed this even under the highest pressures, and conjecture that such an effect must have been caused by other circumstances. Or perhaps valves with flat seats may have been referred to. These ought never to be used, for they are not only proved by experience to be more liable to stick, but they require a larger ground face than conical valves, and are subject to other and greater objections.

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tions. I am not aware that our historians have laid claim to the invention of the safety-valve. Other exceptions might easily be taken to the paragraph in the text.

Weighted valves or plugs opening upwards were used before Papin's time for the purpose of allowing vapour enclosed in a vessel to escape when its pressure increased beyond a certain amount. Some of the ancient steam deities were thus fitted, and apparatus of this description are noticed by Estienne and Lebault, 1574; Glauber, before 1650; and French, 1651. "Papin's claim, therefore, is not to the valve itself, but to its improvements, or rather to the mode of applying it by means of a lever and moveable weight (proposed by him in 1681 for his digester); thereby not only preventing the valve from being blown entirely out of its place, but regulating the pressure at will, and rendering the device of universal application." He did for the safety-valve what Watt did for the steam engine itself, namely, extended and generalized its use; and as long as the safety-valve shall be used, the world will be his debtor. *Vide* Ewbank on Hydraulic Machines.—Tr.

80. I have already spoken in another place of several kinds of safety apparatus, such as fusible plugs, warning bells, sacks, &c., and multitudes of contrivances for the same object may be found recorded.[26] I will only mention that all such as allow the escape of steam when the water level falls, appear to me obviously attended with more danger than they pretend to provide against.

The French *Société d'Encouragement pour l'Industrie Nationale* have, for a long time past, offered a prize for a perfectly satisfactory arrangement for the prevention of explosion of steam boilers. The invention, however, of such an arrangement would pre-suppose an exact knowledge of all the causes of boiler explosions, from which we are unfortunately at present far removed, since almost all we can say on the subject rests upon bare hypothesis alone. We have already seen that regulations for preventing the undue increase of pressure are, alone, insufficient to provide against danger. Undoubtedly the Society would have acted more wisely had they offered a reward for a boiler whose explosion should be unattended with disastrous effects: they would then have laid the axe to the root of the evil, and the state of our knowledge in regard to the causes of explosion would have been but of little matter. With a boiler fulfilling this condition, we may contentedly trust to our ordinary safety arrangements, especially if we take the precaution to secure engine attendants of good character. Such men, when they fulfil their duty in a careful and intelligent manner, afford more security than all the most ingeniously contrived apparatus. If they are ordinarily gifted with the power of observation, they may

[26] The Author gives some references in a note.—Tr.

easily interpret all the appearances which present themselves in the working of the machine, and, aided by a manometer, may deduce therefrom the constant state of the evaporative process. The important requisite is, that the attendant must thoroughly understand and take an interest in his machine; must constantly strive to bring it to the greatest possible degree of perfection; and must take his greatest pleasure and pride not only in increasing its effect, but in maintaining the perfect cleanliness and repair of its individual parts, and the beauty of its external appearance generally. The praise of his engine ought to inspirit him; while its detraction should be to him a source of discomfort.[27] Men of this class can, however, only be retained by those proprietors who themselves take an interest in their engines, and personally show a good example to their inferiors by devoting their own attention to the care and improvement of their machinery.

81. Safety-valves with pistons are sometimes used. A packed piston, weighted for a certain pressure, slides in a cylinder which has a gradual enlargement at its upper end. The piston-rod passes upwards through a guide, and carries the weight. When the steam rises beyond a certain pressure, the piston passes into the enlargement of the cylinder, and the steam finds room to escape round it.

[27] I have noticed with true pleasure the extraordinary interest which an engine attendant in England always feels for his engine. It is his joy, his pride. He rejoices when it is praised, and treats those who find fault with it with pity and contempt. This warm and lively interest generally tends considerably to the exaggeration of the character of the machine, on which account we can but seldom place much trust in the statements of engine attendants as to the useful effect or the consumption of fuel.

The variable state of the packing must, however, produce uncertainty in the action of this apparatus.

82. Thermometers are only of use as safety apparatus when they act quickly, and when their indications are frequently compared with those of other gauges. By themselves they are neither true indicators of the elasticity in the boiler (since low-pressure steam may be overcharged with caloric), nor are they to be trusted for giving warning of other dangers. In my opinion, they may well be dispensed with, being very fragile, and requiring great care in their fixing and management.

PRESSURE GAUGES.

83. Among arrangements for facilitating the control of the pressure in the boilers of high-pressure engines, may be named principally the manometer, an instrument well known. After once proved, it is eminently trustworthy, and becomes indispensable to the engine attendant in regulating his firing according to the varying pressure of the steam in the boiler. In high-pressure engines the ordinary mercury gauge used for low pressure cannot be employed, as the mercury column would be required inconveniently long. This is to be regretted; for this apparatus is undoubtedly more simple and secure, and less liable to derangement than the manometer, which has the evil, that in case of a vacuum being accidentally formed in the boiler, the air above the mercury is so apt to escape. The only way to prevent this danger is either to shut off the communication between the boiler and the manometer by a cock while the engine is standing, or to provide the boiler with a vacuum-valve.

Gauges for steam pressure on the principle of the spring steelyard have often been recommended. Upon an instrument of this description is fixed a small piston, working steam-tight in a cylinder exposed to the pressure of the steam. The more the pressure increases, the higher rises the piston, and the resistance of the spring, increasing in like ratio, is indicated by an index pointer. But it is impossible to expect exactitude in an instrument of this description, where the variable friction of the piston must so much influence the correctness of the indications.

WATER GAUGES AND REGULATORS.

84. The apparatus for ascertaining and regulating the height of the water in the boiler is of the greatest importance. According to the present state of our knowledge, we believe by far the majority of explosions to have resulted from the water level in the boiler having sunk too low, and therefore the indication of this level cannot be too secure and exact.

A host of arrangements have been proposed for this object, and among these the common *gauge-cocks* are perhaps the most imperfect of all. They ought most especially to be banished from low-pressure engines, although they are almost universally used for these, especially in England. But in no case do they give any certain indication of the height of the water in the boiler. When, for example, the lower cock is opened, the water which issues tends to evaporate instantaneously into steam by the reduction of pressure, and it becomes difficult to tell whether water or steam is observed. And when the upper gauge is opened, the water level in

the immediate neighbourhood of the internal aperture of the pipe rises so much (in accordance with a well-known result whenever a current of steam is issuing from a boiler) as often to deliver water with the steam, to a considerable extent, even although the general water level in the boiler may stand at its proper and normal line.[28] Moreover, there are other evils attending the use of these gauge-cocks. The steam or water discharged endangers the observers, besides being the source of much dirt and deleterious moisture in the boiler and engine-rooms. The inconvenience of manipulation of these cocks, compared with others which require but a single glance to read their indication, also point them out as much inferior.

85. Besides gauge-cocks, water gauges are reduced to two kinds; viz., floats and glass tubes, both which are too well known to need description. Both have their advantages and defects. The defects of the float are its sluggishness and want of sensibility;—of the glass tube, its liability to fracture, and to the loss of its transparency after long use.[29] Glass tubes are moreover uncertain in their action, from the liability of their connections with the boiler to be stopped up by dirt in the water. These connections are frequently furnished with cocks, which it is said might be

[28] See the researches of the American Boiler Commission. 'Mechanic's Magazine,' No. 666, &c. See also 'Cornish Engine,' Art. 148: 'Repertory of Patent Inventions,' Sept. 1832, p. 186: 'Bulletin de la Soc. pour l'ind. nat.,' June, 1840, p. 197.

[29] M. Meier, of Mulhausen, has protected the tubes upon locomotive boilers by an exterior additional glass tube, which also shields them from the access of cold air. He has also contrived a simple arrangement for preserving their transparency. These improvements, however, render the apparatus complicated and expensive. See 'Bulletin de la Soc. ind. de Mulhausen,' No. 57.

closed in case of the fracture of the tube; but it seems to me that after such an accident it would be next to impossible to get at them in the midst of the scalding discharge which would ensue.

86. Floats are simpler instruments than glass tubes, and if their defects are removed, are not much exposed to accident. I have in my practice found them always the best and most certain indicators, since I have succeeded in improving their construction. On the old plan, the floats hang on thick wires or rods, which pass out of the boiler through stuffing-boxes, and are attached to one end of a lever whose other end supports a weight of sufficient magnitude to keep the stone floating. This arrangement, however, hinders the motion and free play of the machine: the thick wires, especially if of iron, soon become oxydated, and cause great friction in the stuffing-boxes, which the floats do not possess sufficient force to overcome, since this force is only derived from the difference of specific gravity between the float and the water; or at least they must be of great magnitude in order to act with the sensibility necessary for tubular boilers, where the water receivers are small. I shall hereafter show my improved construction of these floats.

The material of which the floats are made is very important. At first I tried hollow copper bodies, but I found these frequently collapsed, for I could not make the copper sheet strong enough without intrenching too much on their power of flotation. Such floats are also too light and moveable, and, following even the slightest movements in the water, keep in a state of continual oscillation which much detracts from their value as indicators. A good

float should not vary by such slight movements in the boiler, but should remain steady at the line of water level. Stones fulfil this condition best, and they are therefore much preferable to hollow bodies. Of course a part of their gravity must always be balanced by a counter-weight.

87. In my high-pressure engines I have altogether abandoned the plan of regulating the water level or supply to the boilers by any self-acting apparatus. I have found by experience that such arrangements soon become defective and useless, most of them being out of the reach of observation; and when so, they place the boiler in a much worse and more dangerous position than without them.—If floats act upon regulating cocks or valves, these latter soon stick or otherwise get out of order, either through the changes of temperature and the action of the water, or on account of the deposition of earthy matter within them. But the worst of all such apparatus is, that they give the boiler attendants a dangerous idea of security, and tend to make them careless of their duty, and to prevent them bestowing proper attention upon the height of the water in the boilers and the condition of the feeding apparatus. I have always found that in order to make these persons watchful and careful, their duty must not be made too easy and convenient for them. If they know that the water level in the boiler regulates itself, they will trouble themselves little about the feed apparatus at all; but if they have constantly to watch the varying height of the gauges, and thereby to regulate the admission of the water, they are kept in a salutary and intellectual state of activity which prevents them from becoming mere machines, or working by mere instinct like the lower animals. The

caution of the attendants is by this means also extended to the state of the pump and the whole feeding apparatus; and should any defect in the supply be apparent, the cause may be immediately discovered, and a remedy applied before any dangerous consequences arise.[30]

ON THE PROVING OF BOILERS.

88. I will say a few words on this head before I proceed to describe my own improvements.

The general impression is, that a boiler is perfectly secure if proved by hydraulic pressure, before being used, to three times the elasticity of the steam it is destined to contain; and much reliance is placed on this test, especially for high-pressure boilers. For my own part I must honestly declare that I have not participated in this opinion; for I am convinced that a boiler when heated is not to be considered in the same condition as regards strength, as when cold; and that consequently a trial made in the latter state affords no security for the former. If boilers are made of given small diameters, and their strength proportioned to withstand a six or eight-fold pressure,—if they are constructed on correct principles, and above all things in such a manner that an explosion will not entail any considerable danger,—the process of proving is quite unnecessary, and does more harm than good, inasmuch as it tends to expose the metal to an over-straining which may afterwards produce dangerous rents and leaks when the heat comes to be applied. Besides, this process only provides against such dangers as ensue from a gradual increase of the pressure of the steam, and not

[30] *Vide* Pole on the Cornish Engine, Art. 147.

against those much more common ones arising from sudden accidents, such as the overheating of the plates and subsequent flow of water upon them. The Government regulations adopted in many countries with regard to steam engines and their boilers are often immature and unpractical, as may well be believed when we consider that they mostly originate with persons who know the steam engine only by what they hear or read of it. It appears to me that there are no means of proving the tenacity of boilers before used, which shall be perfectly satisfactory and suited to the subsequent conditions of their working. The only security is to be found in the character of the manufacturer for uprightness, conscientiousness, ability, talent for and experience in his calling; and in the skill and honesty of those who work under him. And after the machine has left his hands, the responsibility of keeping it in its pristine state of safety lies upon the user, to whose order, care, and interest it is confided. If Government regulations are to be provided at all, they should be directed more against the engine attendant than the engine builder. This would be to hit the right nail on the head; for in this respect much is and ever will be wanting while temptations to intemperance and dissipation for people of this stamp exist and multiply.

DESCRIPTION OF THE AUTHOR'S IMPROVED BOILERS.

89. Having now, in these remarks upon high-pressure boilers and their apparatus generally, endeavoured to lay before the reader the true principles from which scientific and advantageous improvement should spring, I proceed to describe my own arrangements. My readers may thus be better enabled to judge how far these deserve to be called

improvements, and to appreciate the motives which have led me to adopt them.

I have already remarked that I make use of two kinds of boilers for my high-pressure engines. The first kind serves particularly for small engines of from one to ten horses' power, the second for those of a larger size. Both are tubular boilers, and each shall be described in its turn as exactly and fully as possible.

I. DESCRIPTION OF THE BOILER FOR SMALL ENGINES.

90. This first kind of boiler consists of tubes or cylinders of large diameter, which I construct of plate iron or copper. Of these cylinders I take a greater or less number, and make them of various lengths and diameters, according to the power required and the circumstances of the case; but I never let them exceed one foot[31] in diameter. I always arrange them in two rows, one upper and one lower, and the lower ones are the smallest in diameter. The thickness of every cylinder bears a constant ratio to its diameter; and I use the following proportions for both iron and copper:

For	12 inches	diameter,	the thickness is	$\frac{1}{4}$	inch.
"	8 or 9	"	"	$\frac{3}{16}$	"
"	6	"	"	$\frac{1}{8}$	"

[31] The measure used by the Author in his drawings, and referred to in his text, is the *Hamburgh foot* (Hamburger fuss), which, like our own, is divided into 12 inches (zoll), each subdivided into eighths. This measure is shorter than ours in the ratio of about 15 to 16; but for the sake of simplicity I have allowed the stated dimensions to remain the same in the translation as in the original; and for all practical purposes they may be considered as English measure.

The true length of the Hamburgh foot is

One upper and one lower cylinder together will be called *a pair*.[32]

In fig. 3, such a pair is shown as fixed in the furnace, the latter being represented in a vertical section: *a* is the upper, *b* the lower cylinder.

The two cylinders of each pair are connected with each other by a short vertical tube (*c*), situate either at the front or back end,—the front the best. This tube is usually 10 inches long. Its size is dependent upon that of the boiler. If the latter is 12 feet long, the connecting tube should be 4 inches diameter; if 8 feet long, 3 inches; and for small boilers of 6 feet long, it should be at least 2½ inches diameter in the clear.

The ends of all the cylinders, both upper and lower, are closed with strong cast iron covers: these may be adapted to only one end, but the operation of cleaning is much facilitated if both ends are so provided.

The lower cylinders (*b*) are quite filled with water; the upper ones (*a*) only half filled, the upper half of these cylinders forming the steam space. See fig. 4, where three pairs of cylinders (*a b*, *c d*, and *e f*,) are shown in vertical section; *a*, *c*, and *e*, referring to the steam spaces

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	0·28642	French metres.
or	0·9397	English feet.
or	11·2764	English inches.

A Hamburgh ell contains two Hamburgh feet, or 0·6264 English yards. See Scherer's 'Allgemeine Contorist,' article *Hamburg*.

The above table will suffice if it is desired to reduce any of the dimensions in this work to their true English equivalents. Or, multiply the Hamburgh dimensions by 31, and divide by 33; the result will be the equivalent in English measure.—Tr.

[32] *Eine lage.* I know of no term equivalent to the original, which would answer in this case. I have therefore substituted the one in the text. *Layer* and *tier* give the idea of a horizontal position.—Tr.

in the upper cylinders. The steam spaces of all the cylinders are connected with each other by rising connecting tubes (fig. 5, *g*, *h*, *i*) which open into a common steam pipe (*k*), lying across the boiler. The water spaces are united by similar tubes (fig. 6, *l*, *m*, *n*), proceeding horizontally from the lower part of the covers of the lower cylinders, and opening into a common tube (*o*).

Upon the steam-pipe (*k*) are fixed one or two safety-valves (figs. 3 and 5, *p*), and the index (figs. 1, *p*, and 5, *q*) of the float that shows the water level in the boiler. Upon the connecting tube (*o*) of the water spaces is a draw-off cock (fig. 6, *r*).

The connecting tubes leading to the steam-pipe (fig. 5, *k*) I place as far as possible from the tubes (*c*) which connect the upper and lower cylinders together, in order to prevent the ebullition from the latter carrying water into the steam-pipe and to the engine.

The float also should be as far removed from these latter named tubes as possible, that it may act in still water, and not be subject to disturbance from the ebullition.

The cylinders being open to each other, the water stands at exactly the same level in all. Any disturbance of this level should be participated in as quickly as possible by the whole boiler, and for this reason the water connecting tubes (fig. 6, *l*, *m*, *n*, *o*) should not be too small; for large boilers 2 inches, for small ones $1\frac{1}{2}$ inch diameter in the clear, will suffice.

91. When the cylinders are of iron, I construct them of plates riveted together; but when of copper, I join the sheets with hard solder. The connecting tubes are riveted to the cylinders in all cases.

The riveting of iron cylinders is performed in the ordinary way, but with the greatest care, so that the joints may be perfectly sound. This is the more necessary since high-pressure steam is an exceedingly subtile fluid, and finds its way through the smallest crevices. I use only one row of rivets, and these I drive in the usual manner, *i. e.* red-hot. The rivet-heads I make strong and of large diameter, and the riveted ends I spread out by a stamp to a good extent in a hemispherical form. In this manner they are made to cover well the spaces between the rivets, and when they contract by cooling, they thus compress the plates more perfectly together. In order that the rivet-holes may attain the utmost regularity of form and position, I *bore* them in preference to punching them. I am then enabled, before the operation, to adjust the edges together, which much simplifies the process, and compensates in some degree for the extra trouble. The more exactly the rivet-holes are arranged, the more perfectly are they filled by the rivets, and the better the joint when finished. For plates $\frac{1}{4}$ inch thick, I make the rivets $\frac{5}{8}$ inch in diameter, and set them $1\frac{1}{2}$ inch apart, measured from centre to centre.

92. But notwithstanding the greatest care, riveted iron vessels seldom prove perfectly tight. In order therefore to make them so, and to fit them for holding high-pressure steam, I adopt various contrivances. If the leaks are few and small, I fill the boiler with water, empty it again, having marked the defective places, and let it remain one or two days empty. The leaks then rust up more or less perfectly, and if small, usually become tight; if not after the first operation, at least after its being three or four

times repeated. But if more important leaks remain, I besmear the joints or rivet-heads with the well-known iron cement (a compound of iron filings, sal-ammoniac, and flowers of sulphur, mixed up with water to the consistence of a paste),[33] taking care not to use it in such quantity as to corrode the metal to an injurious extent, and applying it where possible *inside*, that the pressure may rather tend to drive it into the crevices than out of them.

Iron cement is far preferable to any other material for making iron joints. It has the excellent property, that it becomes more sound and tight the longer it stands, so that cemented joints which at first may be a little leaky, soon become perfectly tight.

There is but little ground to fear for the soundness of a well-riveted iron boiler, for in time the action of rust and deposit will stop almost any crevices. In order however to take all precaution, it is to be recommended that some clammy substance, such as horse-dung, bran, coarse meal, or potatoes, should be boiled in the vessel before it is

[33] The following is the best way of preparing this iron cement. Take 16 parts of iron filings, free from rust; 3 parts powdered sal-ammoniac [muriate of ammonia]; and 2 parts of flowers of sulphur: mix all together intimately, and preserve the compound in a stoppered vessel kept in a dry place, until it is wanted for use. Then take one part of the mixture, add it to 12 parts of clean iron filings, and mix this new compound with so much water as will bring it to the consistence of a paste (*dicker brei*, thick pap], having previously added to the water a few drops of sulphuric acid.

Instead of filings of hammered iron, filings, turnings or borings of cast iron may be used; but it must be remarked, that a cement made entirely of cast iron is not so tenacious and firm as if of wrought iron; it sooner crumbles and breaks away. It is better to add a certain quantity, at least one-third, of the latter to the former.

If leaks to be stopped with cement are very large, it may be economized by adding clean river sand, but not to the extent of more than a fourth of the whole mass.

used: a very small quantity also of the same kind of substance may be put into the boiler when first set to work. This will find its way into the crevices by the pressure within, and, gradually hardening, will soon render the vessel perfectly sound.

By these means I have always succeeded in rendering my iron-riveted boilers perfectly steam and water-tight, even for the highest pressure; and I have been much astonished at hearing the complaints of others on this point.

Copper cylinders, if they are well soldered, remain perfectly tight as long as they last, and none of the before-mentioned precautions are necessary with them.

93. In order to fasten the covers upon the ends of the cylinders, whether copper or iron, I rivet upon each end a ring 2 or $2\frac{1}{2}$ inches wide and $\frac{3}{8}$ inch thick, placing the rivets in two rows, those of each row alternating in position. The rivets of the second row from the end (in the upper cylinders 12 or 14, in the lower 8 or 10 in number) are provided with projecting cylindrical heads, $\frac{3}{4}$ inch diameter, and projecting 1 inch: upon these fit the eyes of $\frac{3}{4}$-inch screw eye-bolts, which pass through corresponding holes in the cover, and serve to fasten it against the cylinder end. The cast iron cover is 1 inch thick, and has a strong iron projection cast upon it which fits into the interior of the cylinder. The edge of the cylinder abutting against the cover is fitted with great exactness, and turned if possible; and a corresponding groove is turned in the cover, into which the end of the cylinder accurately fits. A ring of pure soft lead is introduced into this groove, and the joint is thus made tight between the two surfaces. This circular groove in the cover is indispensable,

that the ring of lead may not flatten out when compressed.

I make use of this arrangement, viz., the turned projection and corresponding groove, in all cases where I use lead for the joint, and can strongly recommend it wherever sound and durable joints are required. When lead is introduced between bare surfaces, it is always necessary to turn upon them narrow but deep grooves, into which the lead may be pressed when screwed up, so as to avoid lateral extension.

The arrangements just described are shown on an enlarged scale in figs. 7 and 8. The former is an external view, the latter a section: *a* is the cover; *b* and *c* are eye-bolts, and *d*, *d*, *d*, the cylindrical projecting rivet-heads, upon which they hold: *e e* is the projection on the cover which fits into the cylinder; *f f* is the groove into which the turned end of the cylinder enters, and in which the lead ring is held; *g g* is the ring riveted, by the rivets (*d* and *h*), upon the end of the cylinder.

In order to give still greater security to the covers and to the cylinders themselves in the direction of their length, when of larger diameter, a strong bolt, with a head at one end and a screw and nut at the other, may be passed through both covers, running the whole length of the cylinder. This, however, interferes with the float, and is not necessary for cylinders which do not exceed 12 inches in diameter.

As I have already stated, it is not absolutely necessary that both ends of the cylinders should have loose covers. In many cases, especially with short cylinders, convenient for riveting, one end may be of strong iron plate, riveted on. These ends should, if possible, be hammered into a spherical shape. I must, however, again

observe that the process of cleaning is much facilitated when both ends can be made to open; a consideration of great weight.

94. The water-tube (fig. 6, *o*) connecting the lower cylinders with each other, I generally make of copper. It is best situated outside the back end of the furnace. Into this tube open as many small connecting pieces (fig. 6, *l*, *m*, *n*) as there are pairs of cylinders. They are furnished with strong iron flanches soldered [brazed] on, by which they are screwed to the cylinder covers, the joints being made tight by interposing the *double cones*, hereafter described. One end of the junction tube is furnished with a draw-off cock, for emptying the boilers; the other end is stopped with a blank flanch, unless it is preferred to introduce the feed water by this aperture. In order that the boiler may be completely emptied when the draw-off cock is used, the pipe (*o*) must be connected to the cylinders at their lowest level, as otherwise water would remain within them. For the same reason this connection is best made at the back end of the cylinders, because they are fixed so as to incline a little downwards towards that end.

This pipe and its connections are very apt to be encrusted with the deposit formed in the boilers, and it is therefore necessary they should occasionally be removed and cleaned, a very easy operation if constructed as I have described.

I have in most cases introduced the feed water into this junction tube, for the reason that it would be thus distributed most regularly among all the vessels: but more recently I have found that by this arrangement not

only is the tube more exposed to the deposit of boiler-stone, but that this deposit distributes itself also into all the cylinders, which is not the case when the water is introduced into only one vessel, and that the upper one of the pair. Since the boiler-stone, and especially the carbonate of lime, its prevailing ingredient, first begins to precipitate at the time when, and in the vessels where, ebullition commences, it has a tendency, under the latter named arrangement, to deposit itself, as I have experienced, in the upper vessel alone. It is superfluous to show how much simpler, easier, and shorter this must render the process of cleaning.

95. The connecting tubes between the upper and lower cylinders are made of cast iron when iron cylinders are used. They are of adequate strength, the metal $\frac{3}{4}$ inch thick, and have a strong flanch cast on each end, curved to fit the upper and lower cylinders respectively. The joints are secured with six screw-bolts, $\frac{5}{8}$ inch diameter, to each flanch, and made tight with iron cement laid in as thin a layer as possible between the flanches and the cylinders.

For copper cylinders I make the connecting pipes in two pieces, screwed together in the middle by two strong wrought iron flanches, soldered on to the copper tubes. The joints I have best made of copper rings, of $\frac{1}{8}$-inch copper wire soldered together, whose upper and under surfaces were filed to a sharp edge projecting in the middle. The crowns of these connecting tubes are made of copper, and riveted to the cylinders. I have found this arrangement very suitable to the purpose, and perfectly strong and tight.

In figs. 9, 10, and 11, the connecting tubes are shown on a magnified scale. Figs. 10 and 11 show an elevation and section of the cast iron ones: *a* and *b* in both figures are the flanches, whereby they are fixed to the cylinders. Fig. 9 shows the tubes as made of copper, and connected to copper cylinders: *a* and *b* are the crowns, riveted to the cylinders, *c* and *d* are the flanches between which the copper joint-ring lies. This ring is drawn separately in figs. 17 and 18, which show the sharp filed edges. These sharp edges adapt themselves accurately to the flanches, and form a most secure and durable joint.

96. The steam collecting pipe (fig. 5, *k*) which lies above and across the whole boiler, and is connected to the upper cylinders, is, for iron boilers, made of cast iron. It is in as many pieces as there are pairs of cylinders. Each piece consists of an upper horizontal part (1) and a lower descending branch (2) at right angles to the former, giving the whole the form of a T. All three ends of this piece are furnished with flanches, that on the descending branch (3) being curved to fit the upper cylinder, and the two others (4) serving to connect the various pieces with each other. When thus connected, the two outside flanches of the whole may be used for attaching the pipes to convey the steam away to the engine or elsewhere, as may be required. The steam-pipe (5) leading to the engine is always made of copper and polished. The other end (6) may be used to convey steam to any other apparatus, or to the manometer, &c.; or may be closed with a blank flanch.

Two of the pieces of which the steam collecting pipe

is made must have an additional ascending branch, opposite the descending one, and giving the piece the form of a cross. One of these carries the safety-valve, the other the index of the float. In figs. 1 and 3, both these are shown; in the latter (at *p*) the safety-valve, in the former the float index, the tubes in front of this being supposed to be removed. The whole of the joints of the before-mentioned flanches are made with iron cement.

In copper boilers, all these tubes and pieces are of copper, with strong gun-metal or wrought iron (the latter the better) flanches. The flanches are soldered on, and have projections and corresponding grooves to hold lead jointing, (which is best cut from sheet lead,) as before described. Or else they are fitted for the double cone joint. The descending branches (fig. 5; 2, 2, 2,) are riveted tight upon the upper cylinders. When gun-metal flanches are used, I slip them upon the tubes and turn up the edges of the tubes over them. These edges then form small flanches of themselves, which I solder with soft solder to the gun-metal flanches. When two flanches thus constructed are put together, the small flanches, or ends of the tubes, abut upon each other, while the large gun-metal flanches serve to receive the screw-bolts which hold the joint together. The joint may be made tight by the previously described copper ring, or by the double cone.

97. I will now proceed to describe this beautiful arrangement, the double cone joint. It consists of a short tube, a little smaller in diameter than the tubes to be connected, and whose external surface is turned into the form

of a double cone,[34] or rather of frustra of two cones placed base to base. The ends of the main tubes are bored out, or ground upon a rounded and polished mandrel, so as to fit upon the cones, taking care, however, not to reduce too much the thickness of metal. The cone is placed between these, and the flanches screwed up, when the conical surfaces adapt themselves closely to the bored ends of the main tubes, and render the joint perfectly tight and sound.

The double cone joint is shown in fig. 15 in section: *a* and *b* are the ends of the pipes to be joined, and *c* is the double cone, a view of which is given in fig. 16. Its surfaces are slightly curved, which renders the junction more sound and durable: *d* and *e*, fig. 15, are the flanches of the tubes to be joined, and *f* and *g* two of the screw-bolts which hold them together and press them upon the cone.

This double cone joint is the best that can be made for high-pressure steam. It forms a perfectly tight closure, even for an enormous pressure, and always remains secure and trustworthy. The cones seem to be the best when made of iron, especially if the metal is soft and of good quality. The joint closes best when the edges of the tubes are somewhat sharp. Copper cones are softer than iron, and may therefore be used when the screws are not too powerful.

The double cone joint appears to have been first mentioned by Jacob Perkins, who deserves great thanks for this beautiful invention.

[34] I adopt the Author's use of the term *cone*, although not quite correct, as the surfaces are afterwards said to be slightly *curved* in the direction of their length.—Tr.

It is evident that the opening or canal in the cone must be proportioned to the quantity of fluid passing through it. If it is wished to make the joint without diminishing the passage way, the flanches must be bored out deeper, to receive the cone. This arrangement is exhibited in fig. 15.

98. I allow a greater area to the horizontal steam collecting pipe, than to the pipe which conveys the steam to the engine. The latter, in high-pressure engines, is often made too large. I have found that for 150 square feet of heating surface of boiler, with steam of 8 atmospheres, 3 square inches clear area of steam-pipe is sufficient; or one-fifth of the diameter of the cylinder is ample. The loss by friction of elastic fluids moving in small tubes has been much over-estimated, and is really of but little consequence. I give to the horizontal steam collecting pipe double the area of the pipe leading to the engine; because the steam has in this to make angular motions which tend to interrupt its course and diminish its velocity.

99. The *safety-valve* I use is a conical valve with a three-cornered stalk, whose three surfaces are grooved out to increase the steam way. The conical faces are at an angle of 45 degrees with the axis, and are as narrow as possible for the reason stated in Art. 77. The lever is arranged in the ordinary way, and the weight acts upon the valve through a short rod jointed to the lever, and pressing by a blunt end upon an indentation made in the valve. Care must be taken that this short rod bears vertically upon the axis of the valve, that it may not press it on one side, and so cause undue friction or imperfect closing.

Fig. 12 shows such a valve, with its lever and weight, in elevation; and fig. 13 the valve and seat, in section: *a* is the upper part of one of the pieces of the steam collecting pipe; *b* the valve, *c* the support for the fulcrum of the lever; *d* the lever, with its weight *e;* and *f* the short rod which presses on the valve. Fig. 24 is a horizontal section of the pipe and valve-stalk, showing the three rounded sides of the latter.[35]

The valve, as well as its seat, must always be made of hard gun-metal; the lever, its support, and rod, may be of iron. The lever must be made to move very easily in its fulcrum. The joint must occasionally be oiled to prevent it from rusting, for the escaping steam tends to oxydate all these parts. The lever must be provided with deep notches in which the weight may hang free from risk of sliding: these notches should be so arranged as to give increments of pressure of 10℔s. per square inch on the valve, and the pressure corresponding to each should be engraved upon the lever.

The diameter of the safety-valve, or rather that of the pipe on which it is placed, I make equal to that of the steam-pipe leading to the engine. Too large valves have the disadvantage of requiring unwieldy weights and clumsy apparatus, and are really unnecessary. When it is considered that at 8 atmospheres' pressure, an opening of at most $\frac{1}{4}$ inch diameter will emit as much steam as can be generated by 100 square feet of heating surface, favourably situated over a lively fire; we have no occasion to fear that the dimensions above prescribed, even although the

[35] There is some confusion in the Author's first plate, which I have endeavoured to rectify. The figure last mentioned is omitted altogether. —Tr.

space is somewhat contracted by the valve-stalk, are too small.[36]

100. For a *water gauge*, I prefer, as I have already remarked, floats to all other arrangements. I believe that these, as I construct them, are free from the defects of apparatus of the kind as formerly used; at least I have found them by long experience in the highest degree accurate, sensitive, durable, and trustworthy, when carefully managed.

Fig. 14 shows this float arrangement. Inside the boiler swings a double-armed lever (*a*), its fulcrum (*b*) being supported by a bracket (*c*) screwed to the boiler. The motion of the lever must be free and unimpeded. On the long arm is fixed a conical-shaped stone, 8 inches long, and 4 inches in diameter at one end, tapering to 3 inches at the other. This may be made of firm sandstone, or else moulded and burnt in good brick. It has a hole in its axis which is fitted upon the lever; one end of the stone abutting against a collar (*e*) and the other being fixed by a nut (*f*). On the shorter arm of the lever (*a*) is fixed a cast iron or lead counter-weight (*g*), of such weight as will retain the stone floating with half its mass immersed. The long arm is so bent that the fulcrum (*b*)

[36] M. Köchlin gives ('Bull. de la Soc. de Mulhausen,' No. 48,) the following formula for the diameter of the safety-valve:

$$d = 2{\cdot}6 \sqrt{\frac{c}{n - 0{\cdot}412}}$$

where d is the required diameter, c the heating surface of the boiler in square metres, and n the number of atmospheres' pressure.

The Prussian regulations for steam engines enact, that the area of the opening of the safety-valve shall be $\frac{1}{3000}$ of the total heating surface of the boiler. For high-pressure engines a much smaller area will suffice.

and the short arm of the lever always remain above water, as seen in the figure. If a tension-rod passes through the centre of the cylinder, (see Art. 93,) the float must be double, *i. e.* there must be one on each side the rod. In order to give the stone more cohesive strength, I wrap it round with fine brass wire, taking care on the one hand that the meshes are not too small, and on the other that the weight is not too much increased.

The short arm of the lever carries a hook (*h*), in which is linked a brass wire (*i*) of $\frac{1}{16}$ inch diameter: this passes up one of the head pieces of the steam collecting pipe (*l*), and through a stuffing-box (*m*) into the outer air, where it is fastened upon the short arm of another lever (*n*). This lever swings upon a prop (*o*), and carries on its long end an index to show the height of the water in the boiler. The proportions between the arms of the two levers are so arranged that the index of the outer one moves through the same space as the centre of the float-stone; or, which is the same thing, as the water level. In order that the friction of the vertical connecting wire may be easily overcome in its upward as well as its downward motion, a small weight (*g*), easily adjusted by experiment, is hung upon the long end of the lever. The friction is, however, so trifling, that the motion is sufficiently free, and shows the water level in all its changes. The stuffing-box requires but little packing to make it tight, and the rod is durable and easily renewed when worn. In short, I can recommend this arrangement as one of the most secure, trustworthy, and suitable to its purpose, that can be devised. It is obvious that it must exceed in sensibility the ordinary float arrangement, since the wire (*i*), whose friction in the stuffing-box (*m*) is the

obstacle to motion, is so much nearer to the fulcrum than in the latter.[37]

101. The following *general remarks* apply to my first description of boiler.

I place this boiler in the furnace in such a manner that the heat of the fire strikes first against the lower cylinders, which, being full of water, may receive the fire current on their whole surface. The current flows parallel to the tubes, and passes upwards between them at the back part of the furnace, returning then towards the front along the upper range of cylinders. Now, since these latter are only half filled with water, their upper half must be covered and protected from the fire current. This arrangement is clearly seen in fig. 5, a vertical section of the boiler and furnace. The generation of steam is most rapid in the lowest tubes, which are exposed to the first action of the fire; and as these are so arranged that the back ends lie lower than the front, where they are connected with the upper cylinders, the vapour generated easily escapes into the latter through the connecting tubes. It may carry, however, some little water with it, which will cause the water level at first to rise somewhat in the upper tubes; but this effect soon ceases when the pressure increases, and the steam assumes a smaller volume. When the evaporation first commences, slight crackling shocks may be heard in the boiler, arising from the condensation of the bubbles of steam first formed, by their meeting with cooler water in their course.

[37] The joint *b* may cause trouble: the Author does not show how this is provided against.—Tr.

The passage of the steam from the lower to the upper cylinders usually takes place interruptedly. This may be known from the gurgling noise, which resembles that made by water rushing out of a hole in a cask to which the air cannot gain access. The water must return in a certain quantity from the upper to the lower cylinders, to supply the place of that evaporated, and thus an effect is produced analogous to pouring liquid out of a narrow-necked bottle.

It will be easily understood that a strong ebullition takes place in the upper cylinders immediately over the pipes which open into them from the lower, and it is therefore advisable not to place either the steam-pipes or the float near this situation; they should be as far removed as possible, where the level of the water is less disturbed. If this precaution is attended to, there is little reason to fear either priming or the undue oscillation of the water index.

It is easy to perceive that through the means of the connecting pipes (fig. 5, *k*, and fig. 6, *o*), the steam and water chambers in all the pairs of cylinders are made common, and the steam and water distribute themselves thereby equally among all, even though the heat may often vary in different parts of the furnace. The boiler thus fulfils the difficult condition of retaining the proper water level in all its members, and consequently is not subject to dangerous overheating by any single part becoming dry.

All boilers which I have constructed on this plan provide a good supply of steam with a moderate consumption of fuel. They are light, and easy to manage; and since they contain a large volume of water and steam, in pro-

portion to their heating surface, they work with great regularity and security, and maintain the pressure, if ordinary care is used in the firing, with scarcely perceptible variation. They are, moreover, exceedingly easy to clean, for it will be found that the deposit generally collects against the end covers. I have seldom found any in the middle of the cylinders, and whatever there is may be easily removed with a scraper.

102. I now pass on to the description of my *feeding apparatus*. I endeavour to place this as near as possible to the boiler, so that the man who attends to the latter may have the feed apparatus constantly before his eyes, and be able conveniently to regulate it to the varying requirements of the water supply. The engine itself is, however, generally at some distance from the boiler; and I usually make its connection with the feed-pump outside the engine-room, and work the latter by an eccentric arrangement on the fly-shaft. Wherever possible, I avoid the common form of eccentric, as it is usually made for working the valves of both high and low-pressure engines: it requires much labour in the manufacture, and causes great friction in the working. I generally in lieu fix a flanch with an eccentric gudgeon at the end of the fly-wheel shaft, or else set a pin in a wheel geared into another on the shaft. The gudgeon works the connecting rod communicating with the pump. In most cases I find opportunity for putting the mechanism to move the pump-rod on the box or cistern in which the pump is placed, as shown in figs. 19 and 20. The before-mentioned connecting rod, of which only the end (*a*) is seen, moves the lever (*b*). This lever is provided

with a long slit in which a gudgeon (*c*) is screwed. The connecting rod (*a*) grasps this gudgeon by a notch, in the same manner as the eccentric rod of low-pressure engines (see fig. 21). By means of the slit in the lever (*b*), the gudgeon may be fixed nearer to or farther from the fulcrum, and the stroke of the pump thereby increased or diminished as required. The axle (*d*) moves in plummer blocks (*e*), fixed to the cistern, and carries the lever (*f*), which works the pump-rod (*g*). I case all the gudgeons, and line all the holes of these joints with steel, first forged and turned into form, and then hardened. All link joints in the engine itself I make in the same manner; for I have found it an indispensable precaution if they are to endure long and work easily. Such joints are useless made in brass; they soon wear and become loose, and then their destruction is inevitable. Soft iron is subject to the same objection, and moreover causes much friction. But hardened steel surfaces wear many years without requiring any repair, and do not get loose even if exposed to shaking or concussion. I strongly recommend this plan.[38]

I generally lengthen the lever (*b*) upwards, and provide it with a handle, whereby the pump may be worked when necessary by manual power, after the rod (*a*) (provided also with a handle) has been released from the gudgeon (*c*).

103. My feed-pumps are always piston-pumps, which I prefer to those with plungers. Practice has led me to the preference, and this must always be the Engineer's

[38] All good manufacturers in England adopt this method of making link joints. It is as old as Soho.—Tr.

surest guide. I do not venture to explain how the advantage arises; but experience often negatives the most cogent reasonings and the most scientific calculations, in a manner difficult to explain.

In fig. 23, my feed-pump and its cistern are shown in section. The pump consists of a gun-metal barrel (*a*), accurately bored and polished. At the bottom end is a side pipe (*b*) leading into the valve-box (*c*). Both parts are cast in one piece with the barrel. In the upper part of this box is the discharge-valve (*d*); and in the lower part (*e*) is the suction-valve (*f*). The valves have three-cornered stalks, the three sides being hollowed out to increase the water way, like the safety-valve. The stalk of the suction-valve has underneath, at *g*, a small cylindrical prolongation with a knob: under this lies, on the bottom of the cistern, a small lever (*i*), which, when moved upwards by the wire (*k*), presses against the knob, and opens the valve. By this the supply to the boiler from the pump is stopped, the water returning into the cistern. In order to keep the valve open, the upper end of the rod (*k*) is provided with a ball (*l*) which, when the rod is lifted, may be made to rest on a notch in the braket (*m*) (see fig. 25). I have used this simple arrangement for throwing the pump out of action for upwards of twenty years. It has the great advantage that but little power is required to effect the stoppage, a small force being sufficient to keep the valve open. This property is of especial value where a self-regulating feed is adopted, and when only a limited power is available to control the flow of water. The cocks commonly used for that purpose soon get out of order, and leak, besides forming a considerable addition to the apparatus, whereas my plan is simple and sure, and acts by the existing valve alone.

Another advantage of this arrangement is that it saves the power required to work the pump, while it is thrown out of action.[39] If the suction-pipe is stopped, a vacuum must, at every stroke, be formed under the piston, which not only consumes power, but tends to produce leakage.

In order to prevent the penetration of air into the pump, I use no suction-pipe, but place the whole under water, the top of the working barrel being 2 or 3 inches below the surface. Or if the height of the pump does not easily allow of this latter provision, I make a deep bell-shaped enlargement (fig. 22, *a*) to the top of the pump, which may contain enough water to exclude the air from the piston. If any leaks exist in the packing, the water will have a tendency to exude, from the great pressure in the down-stroke, and will keep the bell full. Any overflow falls by the pipe (*b*) back into the cistern. By these arrangements no air is allowed to come in contact with the pump, and I have found them perfectly effectual.

104. For feed water I always use fresh cold water, not the condensed water from the engine. The latter is indeed as good as distilled, and is less liable to cause deposit; but it carries much grease from the engine with it, acquiring thereby a milky, soapy condition. Now when such water mixes with the cold water in the cistern, the grease collects upon the pump and stops the valves, causing constant danger of derangement. Fresh cold feed water has indeed the disadvantage of requiring somewhat more heat to evaporate it, but the difference is very small in proportion

[39] It is peculiarly applicable to hydraulic presses.

to the whole heat required,[40] and not to be mentioned in opposition to the advantages gained from a regular and secure water supply. With regard to the greater risk of incrustation from fresh cold water, it is enough to remark that in high-pressure boilers this deposit is loose, and causes little inconvenience. When the waste steam is used to warm rooms, the condensed water may be led back into the feed cistern, taking care, however, that the greasy portion proceeding from the engine is not mixed with it. This may be easily prevented by making an enlargement in the exhaustion-pipe immediately beyond the engine, and carrying the greasy water away from this by a small tube.

If it is wished to warm the water before it enters the boiler, this may be best done in vessels interposed between the boiler and the pump; the external surfaces being heated either by the waste steam or the heat from the flues. These vessels then become parts of the boiler, and the water in them sustains the boiler pressure. If the water is heated in these to the boiling point, the greater part of the deposit will fall in them, and arrangements must be made for cleaning them. But under all circumstances the feed-pump must work in *cold* water.

105. The valves of the feed-pump I make as light as is consistent with the necessary strength and durability, especially the suction-valve, in order that it may open freely. The three-cornered stalks should leave a clear opening of at least one-fourth of the area of the pump barrel, and should not be too loose in their guides, lest dirt should enter and stick them fast. It is enough if they

[40] This is shown in the original by a calculation.—Tr.

are so free that the valve will fall by its own weight upon its seat. The edges of the stalk should not be too sharp, lest they wear away and become loose. The length should be about double the diameter. The conical face should be narrow; *i. e.* its width not above $\frac{1}{8}$ the diameter of the valve, which is ample for the highest pressure, if the metal is not too weak. The angle of inclination of the faces to the axis should be 45 degrees. The ring-shaped space between the edge of the valve head and the sides of the valve-box is often made too small: it should not be less than the fourth part of the diameter of the top of the valve.

The suction-valve may be made somewhat smaller than the delivery-valve. The former may then be inserted into and withdrawn from its place through the opening of the latter, and even be ground into its seat in the same manner. This arrangement has many conveniences in the manufacture, since no loose seat is necessary for the lower valve; and it has the advantage that both valves may be removed and examined without disturbing the pump. I have found this advisable, and unattended with any disadvantage.

In small pumps, whose valves are most liable to derangement, it is to be recommended that the apparatus for lifting the suction-valve should be made strong, and so arranged that when lifted it may, if required, be caused to strike against the delivery-valve, and so raise both together. By this means a strong rush of water may be caused from the boiler to the cistern, by which both valves will generally be thoroughly cleaned, and any intervening substances removed.

The delivery or efflux-valve must have a stop-pin fixed over it, to prevent it from rising too high. This is shown

in fig. 23, at *n*: *o* is part of the feed-pipe. Or sometimes I place instead a small cross bridge over the valve, or fix a cross piece upon the valve itself; either of these answering the same purpose.

In order to provide a hold upon the valve when it is necessary to grind it into its seat, I cut a nick in its half-round head, similar to that in a wood screw. In this a suitable tool is inserted when it is necessary to grind the valve.

106. I make the diameter of the pump small in proportion to its length of stroke. This has not only the advantage that the packing is tighter and more easily renewed, but the friction is less, and any air which may enter is sooner and more effectually expelled. In order also further to facilitate the expulsion of the air, I take the precaution of making the piston approach, when at the bottom of its stroke, as nearly as possible to the side opening at the bottom of the barrel; adding sometimes a protuberance on the under side of the piston, which descends beyond the edge of the opening, and so aids in expelling the air along the passage and through the delivery-valve, even when the stroke of the pump may be shortened.

107. The pump working in cold water, the packing of the piston may be made of leather. There is, however, the chance that if the delivery-valve leaks, the hot water from the boiler may find its way back, and injure this kind of packing. I have lately arranged leather packing successfully, by turning a groove in the piston so deep that the leather, when fixed in it, fills the cylinder to such an extent as to make a tight packing. The leather must

exactly fill the length as well as the breadth of the groove. The ends being cut into exact form, must abut together. This kind of packing is shown in figs. 26 and 27: the former represents the piston without, the latter with, the packing: *a*, fig. 26, is the groove; and *a*, fig. 27, shows the abutting joint of the packing. It will, if carefully made, become perfectly tight when wet. If the leather is held fast round the piston, the whole may be introduced into the pump barrel without difficulty, especially if the top of the latter is given a slight conical enlargement. The outer or smooth surface of the packing should be smeared with tallow. This packing will be very durable if the accident above alluded to does not occur. I have used one more than a year. It may be easily renewed when necessary.

If, however, it is feared that the leather may be destroyed by the access of scalding water, a packing may be made of gaskets of loose-spun hemp or flax, wrapped evenly and firmly round the piston, and afterwards steeped in melted tallow. Such a packing is tight and durable, although it will not last so long as leather. In order to make the gaskets hold more firmly on the piston, I roughen the groove in the manufacture by pecking it out all over with a sharp-pointed tool. The packing must never be less than 1½ inch long, and as a general rule, the length should at least be equal to the diameter.

108. I have alluded to the possibility of the hot water returning from the boiler by a leaky state of the delivery-valve. This may also produce danger of the water level in the boiler sinking lower than is consistent with safety. Such an accident may be guarded against in two ways: either by making use of two delivery-valves, one over

the other, both of which the water may pass through successively; or by inserting the supply-pipe only 2 or 3 inches deep in the water of the boiler, so that after a little sinking, steam only may issue. The former plan is most to be recommended, since it is scarcely to be supposed that both valves will forsake their duty at one time. A watchful attendant will soon be aware of the derangement by the sinking of the water level in the boiler, the appearance of steam in the water cistern, and the heating of the feed-pipe; and he may then soon stop the mischief by shutting off the connection between the feed-pump and the boiler. For this purpose a cock should always be placed in the feed-pipe; a provision useful also when any slight attention is wanted to the pump: this may often then be given, and slight derangements remedied, without disturbing the action of the engine.

109. When water runs of itself into the feed cistern, or may be obtained from the pumps of the establishment, it may be kept at its proper height in the cistern by a float-cock, or a waste-pipe, as may be thought best. But if the water has to be raised, it is always better to do this by means of a separate pump than to make use of the suction-pipe of the feed-pump for the purpose. The additional cold water pump may then be a simple lifting pump, worked by the machinery of the feed-pump itself. It should raise somewhat more water than is required, and the surplus be allowed to flow back again by a waste-pipe. This overflow will then always serve as an index to show whether the supply goes on properly. Or if thought desirable, a float in the cistern may be made to sound a bell when the water is too low.

I formerly placed a strainer before the suction-pipe of the feed-pump; but this I found to interfere with the action of the apparatus for raising the suction-valve. It is better to make a frame of fine brass wove wire, 50 or 60 wires to the inch, and to place this in the cistern in such a manner as to divide it into two unequal parts : the water is delivered in the smaller of these, and the feed-pump stands in the larger. All the feed water must then pass the sieve and deposit its impurities before it reaches the pump. The frame may be fixed in a groove, and its edges made tight round the cistern by leather or felt. It may then easily be removed and cleaned. The larger division of the cistern will afford room for the float. The cistern must always be covered, to preserve it as much as possible from the entrance of dirt. It should have a draw-off cock, and should frequently be examined and cleaned; as should also the straining frame. This must be done more or less often, according to the state of the water used.

Soft river or lake water is much to be preferred to hard or spring water, whenever it can be obtained, as producing much less deposit in the boiler. It is liable, however, to be dirty after heavy rains; and in this case it should be collected in reservoirs, and the impurities allowed to subside before it is used.

If there is no vacuum-valve to the boiler, care must be taken to shut the cock in the feed-pipe whenever the engine is stopped, lest the boiler should fill itself with water through the feed-pump.

110. If preference is given to the plunger-pump for water feed, I recommend all the foregoing precautions

and rules to be followed as far as they will apply. It should be entirely sunk under water, and the opening leading from the plunger barrel to the delivery-valve should be immediately under the stuffing-box, in order that any air may escape. There should not be too much play round the plunger in the barrel, never exceeding one-sixth of the diameter of the former. The plunger should always be of copper or gun-metal. All the valves and other parts may be similar to those described above.

111. The *steam gauge* I use is a common manometer. The pipe leading from this to the boiler must always be provided with a stop-cock; otherwise, if a vacuum should be formed in the boiler, the air in the manometer tube may escape. Or as a greater precaution the boiler may be furnished with a vacuum-valve.[41] The steam should not be allowed to act immediately upon the mercury, as it would heat the instrument and affect its indication: this may be prevented by giving the tube a bend downwards before it reaches the manometer. Water will then collect and remain in this bend, and serve as a medium between the steam and the mercury, preserving the latter from the heat of the former. Care must be taken to make the steam-pipe open into the boiler as far away from the water as possible, otherwise there is a danger of its being stopped up with deposit.

[41] These valves, like safety-valves, require constantly to be looked to, or they will stick fast and become useless.

II. DESCRIPTION OF A LARGER BOILER.

112. For a period of now twenty-five years I have been occupied with the attempt to contrive a boiler having the tubes placed in several rows over each other, in such a manner that those of each row should lie over the interstices of the row immediately beneath, and that the heated current should be compelled to pass in zigzag between them, in thin streams, every moment changing its course, and striking, as nearly as possible, perpendicularly against the under surfaces of the tubes. I clearly perceived that when the heat was made to act thus upon a suitable number of rows of tubes, it must be more perfectly applied than when, as in the before-described boiler, the current passed parallel to the heating vessels in a thick stream and with a quick draft.

For a long time I could not succeed in carrying out my plan, since, in spite of all my endeavours, I could discover no satisfactory method of connecting such a large number of tubes with each other and with the necessary receivers, in order that the steam might be led away without interfering with the proper water feed, and also might be so perfectly separated from the water as to leave no danger of priming in the engine, even with small separating vessels. At length, however, after laying the subject aside for a time,[42] the solution of the problem occurred

[42] It has been my custom when I have long brooded over a subject in vain, to lay it by, upon principle, for some time; for I have always found that happy ideas are by no means to be squeezed out of the brain, but rather are dependent on fortunate moments which, the more sought, appear the farther removed. The most interesting matters are after all generally stumbled on. The inventive spirit of man, however active, clear, and powerful, relaxes under the force it is subjected to, becomes partial, confused, and heavy, under

to me. A small model which I constructed of tin plate,[43] gave the most surprising results, and proved that this boiler, even with low pressure, not only removed the danger of the tubes boiling dry, but was also free from the great defect of all tubular boilers, particularly the more modern ones, namely, the danger of water passing over with the steam into the engine.

113. I now proceed therefore to give a description of the boiler itself.

It is divided into three principal parts, viz.:

(A.) The generating or boiling tubes.

(B.) The vessels which serve to lead the steam away from the tubes, and to supply them with water: these vessels I denominate *hearts* (*Herzen*).

(C.) The separators and receivers.

In order to facilitate the explanation I will first give a general description, and will subsequently explain the construction of the several parts in detail.

114. (A.) The *generating tubes* are formed of sheet copper, one line in thickness, and joined with hard solder (*Schlageloth*). They have 4 inches external diameter, and may be from 4 feet 3 inches to 6 feet 3 inches in length, as more or less heating surface is required.

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the continual pursuit of one object, operates perversely, or loses itself in things of secondary importance. Allow it a charitable interval of rest, lead it for a time upon a new and different field, and it collects itself new power to shed light upon the path over which it had before so darkly stumbled.

43 I have always made the models of boilers on which I was experimenting of this metal, for the reason that I could then discover if any parts were subject to boiling dry, by a very simple indication, namely, that in these parts the solder melted, causing leaks, which were immediately detected.

They have at the back end an opening for cleansing them, closed by a screw cover. Their front ends are screwed upon the back plate of the *heart*, in such a way as to be easily removeable in case of necessity; as, for example, when a tube is worn out and has to be replaced by a new one.

The interior space of the tube communicates with that of the *heart* by two oval openings bored through the back plate of the latter, one above the other. The upper one serves to carry away the steam from the tube to the heart; the lower one, to introduce the feed water in a contrary direction. In order to give the vapour a tendency to stream towards its exit openings, the tubes are laid a little on the incline, the back end being, in a length of 4 feet, about ½ or ¾ inch lower than the front end.

Fig. 32, Plate VIII., is a longitudinal section of a boiler and furnace on this principle, the dimensions being given for a boiler of 10 horse-power. A A are the generating tubes; *a a*, their back or lower ends, shut by the screw covers; at *b b* they are connected to the back plate of the heart B: *c* and *d* are the oval openings between the hearts and the tubes. The inclined position of the tubes is seen in this figure.

I lay the tubes in eight rows or tiers, one over another, and in such wise that the tubes of each row stand over the interstices between those of the row immediately below.

Fig. 31, Plate VIII., is a transverse section taken through the tubes. There are seen the eight rows of tubes in the position above described; four alternate rows consisting of one tube less than the other four, this inequality being a consequence of the position: I arrange them in

such manner that the lowest row has the greater number. The space between the tubes I have made about 1½ inch.[44] Between the outside tubes of the widest rows, and the vertical walls of the furnace, I allow ¾ inch space. The manner in which the fire current plays among the tubes is easily seen in the figure.

115. (B.) The *hearts*,[45] as I term them, are flat chambers, from 6 to 8 inches deep. Their height in the clear should in all cases reach 40 or 42 inches; their width depends on the number of tubes in the several rows; the rule obtains that they should be from 8 to 12 inches wider, in the clear, than the outside width of one of the widest rows. The object of this will appear presently. The hearts are constructed of iron; their sides I make usually of cast iron, of such strength as to remove all danger: wrought iron, however, may be used. The front and back plates are of very strong wrought iron plate, the former ½ inch, the latter ¾ inch thick. They are so tied together by several rows of strong iron bolts, that no bending or bulging out is possible.[46] They are also screwed to the side plates with a proportionate number of bolts, equally

[44] I have more lately found that this distance may be increased with advantage, to facilitate in a greater measure the cleaning of the spaces between the tubes. I purpose to increase it to 2, or even 2½ inches, and to provide openings in the side wall of the furnace, through which proper instruments may be introduced for the purpose of cleaning. These openings are shown in figs. 30 and 31 at *a*, *a*, by dotted lines. They must, of course, be tightly closed when the furnace is in action.

[45] This term appeared to me suitable, because these parts are the means of producing a proper circulation of the water through the tubes and other parts of the boiler, in the same manner as the heart is of the blood in the human organism.

[46] I have never found the least bulging of these plates, even with a pressure of 150 ℔s. to the square inch.

strong. The joint is made for the back plate with the ordinary iron cement, and for the front plate with lead, as the latter has to be opened for cleaning.

The hearts have the form of a rectangular parallelogram, with the angles of the interior a little rounded. In most cases their height is greater than their width, inasmuch as a greater number than six tubes in one row is not to be recommended. Fig. 29, Plate VII., shows an external front view of the boiler and its furnace; B is the *heart* in this figure as well as in fig. 32, where it is shown in section: fig. 33, Plate IX., is a section in another direction, and on a larger scale. In all these figures the bolts above mentioned may be seen.

The generating tubes fit into an annular groove sunk in the back plate of the heart. The oval openings which form the communication between the heart and the tubes must come as close as possible to the upper and lower surfaces of the interior of the tube: this is particularly necessary with the upper opening, in order that the steam may pass freely away. The size of these openings is $1\frac{1}{2}$ inch in the longer and 1 inch in the shorter diameter. The manner in which the tubes are secured to the heart is explained farther on.

The internal construction of the heart is peculiar, and of much importance. It is shown in fig. 33, in longitudinal section, looking towards the back plate and the tubes, the latter being represented by dotted lines: *a a* and *b b* are the upper and lower oval openings leading from the heart to the tubes. The upper one, which may be called the *steam opening*, is to allow the steam to pass from the tubes to the heart; the lower one, or *feed opening*, is to introduce the feed water in the opposite direction.

c c c are division plates, of strong wrought iron, fastened steam-tight to the back plate by small ears and screws, and projecting so as to form also a joint as nearly tight as possible with the front plate[47] when this is screwed on: these plates are curved in the form shown in the figure, dividing the heart into several channels *e e*. The use of these divisions is to guide the steam issuing out of the steam openings (*a a*) into the vertical channel *f*, and to keep it out of the way of the feed openings (*b b*), that the proper water supply may not be interfered with. The width of this channel (*f*) depends upon the number of tubes in the rows. I allow for every tube in one of the widest rows, one inch width of channel. The steam passes, carrying usually some water with it, from the channel *f* up the pipe *d* into the separators.

It remains to show how the circulation is completed: *i* is a pipe (which, when the sides of the heart are of cast iron, may be cast with them) passing vertically down the side opposite the pipe *d*, and opening about 3 inches from the bottom of the vessel: through this a stream of water constantly descends from the receivers above, turning up the channel *h*, and gradually supplying the place of that carried away in mixture with the steam, as well as introducing itself through the feed openings (*b b*) into the tubes, to supply the evaporation. The arrows in the figure will clearly explain how the circulation proceeds, and it will easily be understood how the steam, collecting itself by its own levity in the upper part of the chambers *e e*, is guided away by the peculiar form of the division plates, without interfering with the water in the lower part of the cham-

[47] If this joint should not be perfectly tight, it is of no serious consequence, as experience has shown.

bers, or impeding the flow of the supply to the tubes. The steam, as may easily be imagined, carries upwards water mechanically mixed with it, and this is supplied by a gradual reflux, partly from the space *g*, and partly from the chambers *e e*.

The depth of the heart from the front to the back plate should be such that the steam may not form too deep a sheet at the upper part of the chambers (*ee*): I allow for every tube in one of the widest rows $1\frac{1}{2}$ inch depth of the heart. Some space should be left at the top and bottom of the vessel, the former serving for steam and the latter for water room.

e, fig. 32, is a stop-cock for emptying the boiler: *f* is a smaller one, situated one inch above the level of the uppermost row of tubes; it serves as a gauge-cock in case of the usual water gauge in the receiver standing very low, and when doubt is entertained (before fire is put under the boiler) whether any of the tubes are dry. If water flows from this cock, the vessel may be heated, especially as the level rises when the water begins to boil.

From the upper part of the *heart* rise two pipes, (*a* and *b*, fig. 29,) of which incidental mention has already been made. One of these (fig. 29, *a*, fig. 32, *g*, fig. 33, *d*) serves to carry away the steam from the heart into the separators; and its cross section, an oblong rectangle, must have its dimensions proportionate to the steam-generating surface of the tubes; namely, for every 10 square feet of surface, the pipe should have about 1 square inch area in the clear. This pipe has a curved flanch (fig. 32, *h*, fig. 33, *l*) by which it is fastened with screw-bolts to the separator, and the joint made tight with iron cement. If the sides of the heart are of cast iron,

this pipe as well as the following one may be cast upon them. The method of securing them upon wrought iron sides is shewn in figs. 45 and 46.

The other pipe (fig. 29, *b*, fig. 33, *i*) is of smaller area, viz. 1 square inch to every 25 square feet of heating surface. In every other respect it resembles the former one. Its use has been already explained, namely, to lead back the water into the *heart*. When the sides are of wrought iron, this tube must be a separate wrought iron one inserted into the heart, and reaching nearly to the bottom.[48]

116 (c.) The *separators* and *receivers* (figs. 31 and 29, *c* and *d*) are always of wrought iron, formed of plates $\frac{1}{4}$ to $\frac{3}{8}$ inch thick, well riveted together, and provided with strong cast iron end covers, similar to those in my first-described boiler. The diameter of these vessels must never exceed 18 inches, this size being sufficient for the largest boiler.

If only one heart is used, one separator and one receiver of small diameter are sufficient; but when much power is wanted, it is better to make use of more hearts than to increase the number of tubes beyond six in each row. Two of these, with tubes 6 feet 3 inches long, and six in number in the lowest row, furnish steam enough for an engine of 60 horse-power.

The separators and receivers are both of equal dimensions, and are placed horizontally, as shown in the figures. The pipe which conveys the steam from the heart enters at the front end of the separator (*c*), while the steam and the water are carried from the back end into

[48] These two pipes might, to keep up the analogy, be called an artery and a vein respectively.—Tr.

the receiver (*d*);—the former by the pipe *m* connecting the upper part, or steam space, of the two vessels together; —the latter by the tube *n*, forming a communication between their lower or water spaces. Both these connecting tubes have equal area, namely, 1 square inch to 25 square feet of heating surface of the tubes. The steam is carried to the engine from the front end of the receiver, while the water descends, also from that end, by the pipe *b* into the heart, to supply the place of that evaporated and carried up in mechanical mixture with the steam. The receiver is also provided with a safety-valve or valves, and an index float, all similar to those formerly described. These as well as the steam-pipe should be as near the front end as possible, where the water is most at rest.

The dimensions and proportions of the separators and receivers depend on the cubic content of the hearts. I have adopted very simple rules on this point, and have found them to answer all my expectations and requirements, although this boiler is yet comparatively in its infancy. As far as my experience has at present gone, I recommend that the cubic content of the separators and receivers combined, should be equal to the sum of that of the hearts and generating tubes. The length should exceed that of the boiler-tubes by one-half, and when much room is required, the number should be increased, rather than that they should exceed 18 inches in diameter.

A large boiler of this description, which I have already constructed for an engine of 30 horse-power, has two hearts, each with twenty-eight boiling tubes, lying in eight rows, one above another; and I have used two separators, with a single receiver between them, and connected with the

hearts in the manner shown in the sketch, fig. 52, Plate XI. This boiler has not only fulfilled, but far exceeded my expectations; the heat is so perfectly applied, the steam production so regular, the water level so quiet, and the whole so safe, trustworthy, and convenient, that its advantages in these respects can seldom be equalled in the most perfect boilers of the ordinary construction.

117. The action of this boiler has already in a great measure been explained. The tubes abstract the heat from the fire current passing among them, and impart it to the water within. The steam collects in the upper part, and passes through the upper oval openings into the heart, an operation facilitated by the inclined position of the tubes. The steam having reached the interior of the heart, follows the direction given it by the division plates, flowing upwards and sideways into the canal *f*, (fig. 33), and thence by the pipe *d* (or *a*, fig. 29) into the separator (*c*). When the dimensions are suitably proportioned, this goes on without much disturbing the water in the lower part of the channels *e e*, (fig. 33), which constantly covers the lower oval openings, allowing the water at all times to flow into the tubes to supply the evaporation. This water may, however, gently follow in some measure the direction of the current of the steam, being supplied constantly afresh from the canal *h* and pipe *i*. The steam, when it reaches the pipe *f*, rises unhindered through that and the pipe *d* into the separator, and in so doing carries water along with it, causing a strong ebullition in the fore end of the separator. Since, however, the water surface in this vessel has a considerable extent, the steam, passing towards the hinder part of the vessel, finds room to develop

itself, separating continually more and more from the water, and at the back end this separation becomes complete. The steam and water then pass quietly through their respective pipes (*m* and *n*) into the receiver, in which a perfectly quiet water level is maintained, both fluids moving gradually towards the fore end, where the steam is carried off to the engine, and the water is returned to the heart, to pursue its labyrinth-like way as before. The water thus follows a constant circulation, from the heart into the separator, from this into the receiver, and back into the heart again.

I have found this arrangement perfectly satisfactory, not only in preventing water being carried with the steam to the engine, but also in retaining a perfectly quiet water level in the receiver, even when the water surface bore but a very small proportion to the evaporation. How seldom ordinary tubular boilers fulfil these conditions is well known.

118. I now proceed to describe the parts of this boiler more in detail.

I have already said that I make the generating tubes of copper soldered together. I use for this purpose sheet copper of one line in thickness,[49] which, however, in bending generally increases to $\frac{1}{10}$ inch. I lay the soldered joint either downwards, where it may be securely covered with water, or upwards, where it may be protected by a coating of ashes from the too great action of the fire.

The back end plate is of wrought iron, $\frac{1}{2}$ inch thick:

[49] This thickness is abundantly strong enough when the principle mentioned in Art. 50 is taken into consideration; namely, that the tubes should form the weakest part of the boiler.

it is turned in the lathe, and has a furrow $\frac{1}{4}$ inch deep, formed on the outer edge, in which the end of the copper tube exactly fits, and is made fast by soldering. The plate has a hole in the centre 2 inches in diameter, which serves for the purpose of cleaning the tube, and which is surrounded with a sunken groove $\frac{1}{4}$ inch wide, to receive a projection on the cover. The cover is oval, its long diameter being equal to that of the end plate: it has a projection 2 inches diameter, which enters deep into the cleaning hole, and round this another, fitting into the above-named groove. The two oval ears are perforated for screw-bolts, the bolts themselves being tapped, riveted, and soldered into the end plate before it is fixed to the tube. The cover is fastened down by nuts, and the joint made tight by a lead ring placed in the groove surrounding the opening.

Figs. 34, 35, 36, 37, Plate IX., show these arrangements. Fig. 34 is a section of the whole; fig. 35, a back view of the end plate without its cover; fig. 36, the same with the cover screwed on; and fig. 37, the side view of the cover only: *a* is the large or centre boss on the cover, projecting into the cleaning hole (*b*) in the end plate; *c*, the smaller projection, entering into the sunk groove, and compressing the lead packing ring; *d d*, the screw-bolts. In fig. 34, at *e e*, is shown the manner in which the end plate is set and soldered upon the boiler-tube.

The manner in which the opposite or front end of the tube is fixed upon the back plate of the heart, is somewhat more difficult than that above described. This end is surrounded with a wrought iron ring $1\frac{1}{2}$ inch wide and $\frac{1}{4}$ inch thick, fast brazed on, in order to give the requisite strength and firmness to this part of the tube, and to pre-

sent a wide surface of iron for the purpose of fastening the joint between the tube and the heart plate with iron cement. On the inner surface of the tube are riveted firmly (and, when possible, also soldered) two iron ears, set about $\frac{1}{4}$ inch from the end, each having a square recess of about $\frac{3}{4}$ inch wide hollowed in its back end, in which lies the hinder part or arm of the T-shaped tie-bolt, so as to hold by these recesses upon the tube without turning round. The bolt itself is in the screw about 1 inch diameter; it passes through the heart plate between the two oval openings, and is screwed up on the front side by a strong nut. The tube is thereby drawn firmly into a groove $\frac{1}{4}$ inch deep, prepared for it in the heart plate, and the joint is made tight by iron cement. By loosing this bolt, any tube may be easily removed, and repaired or replaced by a new one when necessary.

Figs. 38, 39, 40, show the joint of the fore end of the tube: *a* is the heart plate, with its annular groove *b* for the reception of the tube; *c c*, the oval steam and water openings; *d*, the iron ring, strengthening the end of the tube; *e e*, the ears inside the tube; and *f*, the tie-bolt, shown separately in fig. 40.

119. The heart may be constructed in different ways, according as cast or wrought iron is used for its sides. I have hitherto used only cast iron, and have found it perfectly suitable and secure. This material spares much labour and expense, as the bolt-holes and pipes may be formed in the casting.

Fig. 33 shows such a strong cast iron frame, 3 inches thick, forming the sides of the heart. The pipes *d* and *i* are cast upon it. The bolts for the cover plates pass

through this side frame, but have a square shoulder let into the cast iron on the front side, which not only prevents their turning round, but offers a resistance when the back plate alone is screwed up, so that the front nuts may be loosened, and the front plate of the heart removed, while the back plate and sides remain firmly fixed together, and may indeed be regarded as a single piece. Fig. 41, Plate x., shows a part of the cast iron side piece, with the front and back plates, in section, and four bolts. At *a a* are seen the head-like square shoulders; *b* and *c* are the fore and back ends of the screws respectively; *d*, the back cover plate, and *e*, the front one.

Figs. 42 to 47 show methods proposed for making the sides of wrought iron. They will be easily understood without description.

The front plate of the heart, which has often to be removed for cleaning, should be made tight with a lead joint; and therefore suitable preparation must be made to prevent the squeezing out of the lead plate sideways. The back joint is made with iron cement, and this does not require to be opened.

I have already mentioned that the back and front plates are braced together with several rows of strong tie-bolts passing through both. The bolts of the tubes may be used for this purpose in a manner which will be easily understood from fig. 48. They are not required in every tube, but may be disposed as in fig. 29, about 8 inches apart from one another. I have never seen the least bulging even when the pressure has exceeded ten atmospheres. In fact these plates, when tied and connected in the way I have described, are of such a strength that they cannot possibly give way: the safety of the hearts

may therefore be relied on, or at least it is matter of certainty that they will not be the first parts of the boiler to explode.

120. The separators and receivers need little description, since they are precisely similar to the vessels I have described under the name of cylinders in my first kind of boiler. They are of iron plate, riveted together, closed at each end with cast covers, and the joints made tight with lead rings. They are provided like them with a similar float index and safety-valve, and in them is introduced the pipe for feed water. It is indifferent whether this latter be in the separator or receiver, care being taken, however, that the opening be in a situation where the cold water may mix as quickly and perfectly as possible with the hot, before it enters the heart, that no injurious sudden cooling of the cast iron may take place: with this view I have generally preferred introducing it in the separator.

The steam and water connecting pipes between the separator and receiver I prefer to make of copper: they are all provided with wrought iron flanches; the joints of the steam-pipes *m* are made tight with iron cement; while those of the water tubes *n*, owing to their frequently requiring removal for cleaning the cylinders, should have a lead packing, or a thin flat copper ring, wrapped round with hemp, and smeared with a cement made of pulverised chalk, linseed oil, and red lead. The water communication tubes must also be so constructed that they may be easily cleaned from deposit, as I have described in my former boiler.[50]

[50] This boiler is yet in its infancy, and therefore I am not prepared to say that further experience may not dictate some improvements in the construction

121. I must now say a few words as to the most suitable modifications of this boiler, and its several parts, for different degrees of power.

The amount of heating surface is determined not only by the number of tubes, but also by their length: this latter, however, should never be more than 6 feet 3 inches, or less than 4 feet 3 inches. The number for a single heart should not be above forty-four or under twenty; *i. e.* six or three in the lowest row. These limits, and a variation in the number of hearts, allow all gradations of power which can be required. But the proportions, between these limits, must depend on circumstances, and be determined by the engineer. The number of tiers of tubes I recommend to be always *eight*.

When one heart is used, the separator should be fixed on one side of it, and the receiver on the other. When *two* hearts are used, one separator is placed on either side, and one receiver in the middle. Fig. 52 is a view of the boiler of an engine at Plau, constructed in this way. With *three* hearts, I would arrange two in the above manner, and give the third a separator and receiver of its own. *Four* should be placed as two and two. Of course the whole of the receivers must be connected by a common steam-pipe. Fig. 53, Plate xi., shows the method of making the water communications when two hearts are

of its parts. It is my purpose to endeavour to bring it to the greatest degree of perfection by the most careful experiment and study, and I shall make public any important results to which I may be led.

[I am enabled to state that the later experience of the Author has enabled him to make some most valuable improvements in the construction of this kind of boiler, particularly in economizing the cost of its manufacture. He is now preparing a description of these latest improvements for publication. —Translator.]

used: *a* and *b* are the two separators; *c*, the receiver; *d*, the water connecting pipe between the three vessels. At *e* is a bulb or enlargement of the tube, to give the water more space at this point of junction; and the pipe *f*, which has to receive the water from both separators, is made double the area of the pipe *d*. All the water connections should reach quite to the bottom of their respective vessels.

122. Let us now try this new boiler by the principles I have already laid down for the construction of tubular boilers; and we shall find that it corresponds more than most former ones with the conditions such boilers must fulfil, if they are to approach perfection.

The tubes have a moderate diameter;—so large as to develop a proper quantity of steam, without danger of too violent ebullition, or boiling dry, as well as to allow a constant and quiet water supply, and to remove all chance of damage by overheating;—yet so small, that they hold no dangerous quantity of water and steam, and cause no destructive consequences in case of explosion, but open with a simple rent. Their heating surface and cubic content are in such favourable relation to each other that the steam formed within them takes only a small volume, and displaces but little water. These favourable circumstances have been proved by many direct experiments, undeniable facts, and long practice, which leave them no longer doubtful. The tubes are the steam generators of the boiler; these only are liable to deterioration, and to them alone is fear of danger confined: their construction, however, is such as to nullify this fear. The bursting of one of such tubes would be nearly isolated, and bring no

destructive consequences from the general body of the boiler, as the latter could in such case only empty itself through two small openings, not large enough to allow a greater body of steam and water through than might pass away through the bars of the grate, or up the chimney, without collecting in and bursting open the furnace.

Lastly, the tubes lie so deep below the water level that a want of water in them is scarcely likely to occur, or if it does, those tubes are first uncovered which are exposed to the least heat of the fire current. By this, one of the principal sources of explosion is avoided. The tubes, if heated red-hot, have but a small mass of metal to cause mischief, and are so separated from the boiler that no injurious action going on in the tube can have any dangerous influence on the boiler as a whole; an instantaneous development of steam must therefore confine itself to and exhaust itself on the tube alone. I cannot give this circumstance too much prominence: it is as peculiar to this boiler as it has been hitherto unattained in others, and it appears to me to offer high promises for the prevention of danger with high-pressure engines. My boiler consists of a number of small boilers, which exercise but little influence on, and have but little connection with, each other; this connection being sufficient for all good purposes, but too little for all bad. The vessels have, even if they burst, no destructive action on each other, and their construction and size are such that no danger worthy of consideration is to be apprehended from them.

123. The tubes may be cleaned from deposit in a manner at once easy, convenient, secure, and speedy. As soon as the back covers are taken off, free access may

be obtained to the interior of the tube, which may be then cleaned by means of an instrument of the form shown in fig. 49, Plate x. The oval openings are easily cleaned from the heart, when the front plate is removed. Stony deposit is not often found in the lower tubes, but increases at a higher level, most being in the upper tiers;—an advantageous circumstance, since the lower tubes are thereby less exposed to damage from the intensity of the fire, while in the upper ones the heat has less power.

In the hearts, also, I have seldom found precipitate in a stony form; what there is, collects mostly in the lower part, but always in a loose state; and this may be much diminished by occasional blowing off by the cock at the bottom of the vessel. Upon the division plates, I have found none at all, it being probably driven away by the circulation and ebullition. Of the separators and receivers, that vessel only contains deposit worth notice, in which the feed water is introduced: it is, however, very easily removed.

It might appear that the cleaning of such a boiler takes much time, from so many bolts being required to be loosened. When it is considered, however, how long one of the ordinary large boilers must stand to cool (often more than twenty-four hours) before any one can venture into it, and what immense time and trouble are expended in chiselling off the boiler-stone, in such a confined and dark place, the work with my boiler must appear trifling in comparison. The bolts may be unscrewed while the boiler is yet tolerably hot, and the deposit is more friable and more easily removed at a warm temperature, besides being in a much more loose condition in this kind

of boiler than in the ordinary one. The whole may be done generally before the cleaning of a large boiler could be commenced. The operation in the Plau boiler occupies scarcely one day.

How often such a boiler should be cleaned, depends on the nature of the water. If hard spring water is used, the oftener the boiler is cleaned the better: but soft water should always be preferred where possible; it will well repay extra trouble and expense to obtain it. Frequent blowing off is advantageous; I would recommend that one or two cubic feet should be blown off every hour.

124. The remaining advantages of this boiler may be briefly summed up.

The hearts are so strong that danger from them is out of the question; they fulfil all necessary conditions for low as well as high pressure; and they are little, if at all, subject to the deteriorating action of the fire. The back plate is the only part thus exposed, and this is almost entirely occupied by the tubes. The under surface, which, however, is not over the most intense heat, may easily be protected.

The separators and receivers are strong and durable; and the connecting pipes fulfil all required conditions: they separate perfectly the steam from the water, and maintain a supply of dry steam to the engine, as well as a quiet water level in the receiver.

The boiler holds water enough to insure an equable generation of steam; a very difficult condition in tubular boilers. According to my experience, at least 1 cubic foot of water space should be allowed in tubular boilers for 10 square feet of heating surface, and my boiler fulfils this condition.

The steam-room stands in a favourable relation to the content of the cylinder.[51] Watt stated that the former should be at least eight times the latter; mine holds nearly twenty times as much, when it is regularly supplied with water, and therefore the oscillations of the manometer become very small.

And lastly, I must mention the advantage of this boiler in its favourable and economical application of the heat; particularly in the circumstance that a very short time, namely, half or three-quarters of an hour, suffices to raise the heat from a cold state to such a degree as to supply steam of the proper pressure for the engine. This is an advantage of which certainly very few boilers can boast.

125. I am not prepared to speak positively as to the applicability of this boiler to marine engines, where a great deposit from salt water takes place, but I do not anticipate difficulty, if the tubes are given a larger diameter, say 6 inches, and the hearts a greater depth; the tubes may be then longer, and will not be in so much danger of becoming stopped up. As the brick furnace is inapplicable on shipboard, the masonry may be replaced by flat chambers, of the description shown in fig. 50, Plate x., strongly bolted together, and furnished with cast iron division plates *a a*. The tie-bolts pass through *b b*. A circulation will go on in these vessels in the direction of the arrows: *c* is a pipe to lead the steam generated into the separators, while the water returns through the pipe *d*. Moveable covers must be provided for the purpose of cleaning.

[51] Or in expanding engines, to the content of that portion of the cylinder to be filled with steam from the boiler; in my engines one-third.

The separators have a great advantage in lying horizontally, owing to the increased water surface; but cases may occur where a vertical position is more advantageous; as, for example, where the boiler is unsteady and subject to oscillating motions, as on shipboard. In this case it would be advisable to increase their diameter, at least to 2 feet; or the requisite object may be attained by giving them a sufficient height, or using a greater number. They might be placed round the chimney, and covered with a plate-iron casing, agreeable to the eye, and strong enough to stand rough weather.

126. I have lastly to bring to mind, that when I speak of the heating surface (*Feuerberührungsfläche*) of a boiler, I always intend to be understood the whole of that surface of the same which is exposed externally to the heat of the furnace, and covered internally with water. In all calculations I employ this without deduction, and disregarding whether any individual parts may be exposed more or less favourably to the action of the fire. The power of the surface as regards steam generation must vary much, according to the difference in position, and therefore, in calculating the actual effect, we can only speak of a mean or average value, applicable to all surfaces except vertical; for what certain parts may gain by their more favourable position, is supposed to be lost by the more unfavourable situation of others. In the case of tubes which lie altogether in the fire, the upper surfaces are but little effective in steam production; while the other portions of the periphery, the lower surfaces in particular, are so much more favourably disposed as amply to counterbalance the disqualification of the former. That

this is really so, is proved by the extraordinary evaporative power of this boiler, which experience has shown to reach a high degree, in proportion to its heating surface.

The upper surfaces of the tubes usually become soon covered with ashes, which form a bad conductor of heat: this is advantageous, and promotes their durability, by protecting the part of the tube where the steam collects from the too fierce action of the fire. This part however is but narrow, and is in no danger of remaining long dry.

THE FURNACE.

127. The furnace is one of the most important parts of the high-pressure engine. The whole action and power of the machine depend on its construction, and on the effect obtained from it, inasmuch as fire is the prime agent. We cannot therefore bring too much industry, exactitude, and intimate knowledge of the subject, to bear on the construction of the furnace, in order to attain the two great objects of its action; namely, first, to produce as perfect a combustion of the fuel as possible; and secondly, to apply as much as possible of the heat so developed, effectively to the boiler. These two requirements for a good furnace are, however, not so easily satisfied. We are as little acquainted with the conditions under which the whole of the caloric may be perfectly developed from the fuel, as we are enlightened as to the best manner of applying the heat to the boiler. I will impart, as briefly as possible, my views and experience concerning the construction of good furnaces for high-pressure engines.

128. One of the first considerations connected with the

subject is, whether it is particularly advantageous[52] to make use of a furnace of masonry, or whether those boilers have advantages which contain the fire-place within them, and in which the flame is led along flues surrounded on all sides with water.

It is a very general opinion that the masonry of a brick-built furnace consumes much heat, and robs it from the boiler. It is supposed that the heat is much better applied when the fire, burning immediately within the body to be heated, can radiate to it on all sides. If this reasoning expresses some truth, it also contains much sophistry. I will here again bring to mind what has been already said as to the disadvantages of boilers with inner fire-tubes, with reference to the combustion of the fuel; namely, that in such fire-places the heat is too quickly absorbed from the current over the grate, before it has developed and collected itself with proper intensity, and thereby an imperfect combustion takes place, and much smoke is produced. A brick oven certainly takes up much heat, but this seldom penetrates so into the mass that the outer walls reach a high temperature and radiate much caloric away, particularly when the masonry is thick enough, and is provided with suitable air spaces to prevent the conduction from the interior to the exterior.

If the interior of a furnace is strongly heated, it acts advantageously upon the boiler when the firing is temporarily lowered, since the radiation from the furnace supplies the want of heat from the fire, and thus causes a

[52] *Zweckmässig*, suitable or well adapted to the purpose or object in view. This most useful word has, unfortunately, no corresponding one in English: it occurs in this work almost in every page, and each time has to be translated by a circumlocution.—Tr.

more regular supply of steam. Moreover, when the engine stands still, this condition of the furnace retains the boiler long in a favourable degree of temperature, especially when, by shutting the damper, the penetration of cold air is excluded; and this saves much expenditure of fuel when the engine has again to be set in action, as, for example, in the morning, after standing still all night. It will often happen, that after stopping seven or eight hours the boiler is still found at nearly boiling temperature, and in this case but very little additional fuel is required to get up the steam. I have frequently had proofs of this in my own engines. It is certain that the weight of this circumstance ought to determine us rather to prefer than to reject the furnace of masonry, especially when it is considered that boilers with internal fires are generally much exposed to radiation from their highly heated sides to the outer air; for this must evidently cause a greater loss than could occur from the more moderately heated sides of a brick furnace.

In many circumstances the internal fire is usually considered preferable; as, for example, where the boiler stands in wooden buildings, on shipboard, and the like; where, with masonry, there would be danger of fire; or where the boiler is in motion, and has to withstand shocks, as for locomotives. It is possible, however, to imagine good furnaces of masonry, not exposed to the like danger, and capable of extensive application in steam vessels and other similar cases. Such are the furnaces set in cast iron frames, which are occasionally found on board American steamers.[53] The masonry must be so secured as not to

[53] Marestier, 'Mémoire sur les bateaux à vapeur des Etats Unis d'Amérique.' Planche IX.

be injured by concussions, and should be provided with air spaces to lessen the conduction of heat to the iron casings. It would be indeed unfortunate for the high-pressure engine if tubular boilers could not be used on board steamers, since it possesses all other properties which render it most especially appropriate for steam navigation.[54]

129. I pass on to consider how a furnace of masonry should be constructed, in order that it may well answer its purpose.

With reference to the bricks, none should be used for any part, except such as are perfectly hard burnt and stand heat well: all those of the ordinary material must be laid in such manner that no part is exposed to the direct action of the fire, and they must be cut, where necessary, in order to fulfil this condition. Where a stronger degree of heat acts, the use of a fire-proof material, as fire-stone or fire-brick, is indispensable: in those parts of the flues at a distance from the fire, common bricks may be applied. I have remarked with much astonishment, that lime mortar is often used for steam engine furnaces; it is much preferable to use a loam[55] not too rich, as cement for the fire work; lime soon loses its cementing power by

[54] The Author might have enlarged the discussion upon this topic with advantage; it is most important, and the state of knowledge upon it is very unsatisfactory. The principal kinds of boilers which contain the fire-place within them are, Trevithick's or the Cornish boiler, the locomotive boiler, and that commonly used on board steam vessels. The Cornish boiler is economical and works well; it does not appear subject to the defects alluded to in the text. The others are less perfect, but we know very little about their actual condition as regards economy.—Tr.

[55] The loam (*Lehm*) spoken of by the Author is a mixture of a peculiar clayey earth with sand.—Tr.

the action of heat, becomes loose, and falls to pieces, while loam burns harder, and becomes thereby firmer and more binding. In the setting of fire-stone, or brick, it is a good plan to use a cement composed of a dust from the fire material itself, mixed with fat loam; or to add to the loam some coarse sand, ashes, and common salt.[56]

It is especially desirable that the masonry should be properly secured with cramps, especially where exposed to much heat, in order to prevent it from giving way and cracking by the expansion. Wherever possible, all arches or vaults in the furnace should be avoided, or at least should only be constructed where the heat is not great, and where they have but a light load to carry. In the case where it is necessary to support the end of a vessel over a door opening, it is advisable to use a cast iron plate made to cover the front wall of the furnace, and upon which the vessel may rest. This plate may then also serve for the frame of the fire-door or doors, is not likely to be injured by their opening and shutting, gives the whole an agreeable appearance, and helps to secure the neighbouring masonry. The latter may be further fastened by casting or screwing a projecting rib upon the iron plate: wrought iron bars should never be used for such purposes; they soon become red-hot, and then bend, and by great heat are quickly destroyed.

All parts of the boiler lying free must be covered, to prevent the loss of heat by radiation: the disadvantages of a neglect of this precaution have been before mentioned.

Different methods have been adopted in order to pre-

[56] We have in England what is well known as *fire-brick*, which, when set in *fire-clay*, answers every purpose where fire-proof masonry is required.—Tr.

vent the too great radiation of heat from the exterior of the furnace itself. It has sometimes been given a covering, with ashes placed in the interstice; or fixed in a small separate chamber, perfectly closed: sometimes thick walls alone have been depended on, or interstices have been introduced in the masonry.

I consider the two last methods the best, and the latter the preferable one of these. It requires the least material, and is the most perfect protection. The furnace is surrounded with a second thinner wall, like a covering, between which and the furnace itself is a stratum of air; this, if at rest, acts as an imperfect conductor, and hinders the transmission of heat between the two. Thick walls are not so economical, but have the advantage of offering a greater resistance in case of a slight bursting of one of the tubes. I have in my engines always found walls of 12, or at most of 18 inches, amply thick enough.

130. Much controversy has taken place between scientific men as to the height of the chimney for steam boilers. Some hold that high stacks of 70, 80, or 100 feet, are indispensable to produce a proper draft, while others contend that the same result may be obtained with lower ones.[57] According to my opinion and experience, both sides are right, and we have only to determine with precision the cases in which the truth lies more on one side than the other. I distinguish here the following circumstances:

[57] Peclet has treated this subject very comprehensively in his Treatise on Heat. It has also been further illustrated by M. Penot, in a learned paper entitled 'Mémoire sur la manière de déterminer les dimensions d'une cheminée.'—*Bulletin de la Soc. Indust. de Mülhausen.*

(*a.*) When the boilers are of considerable length and breadth, and the flues are so situated that the current must travel a considerable distance horizontally, passing through and round the boiler many times, and often descending or making angular turns;—high chimneys of 50 to 80 feet are much to be recommended, and in many cases indispensable.[58]

(*b.*) If, however, on the other hand, there are only vertical, or more vertical than horizontal flues, or if the latter are only of short length, and no descending currents;—then the chimney may be much lower, say 20 to 40 feet, or even, where only vertical flues exist, still less than this, if circumstances allow.

(*c.*) The kind of fuel used has a great influence on the necessary height of the chimney. According to my experience, wood requires much less height than turf, turf less than coal, and coal less than coke.

(*d.*) Finally, the proximity of high buildings, trees, towers, or other high objects, also requires much consideration. In most cases, however, it appears sufficient to make the chimney higher than the highest point of the neighbouring objects, and as far removed from them as possible. There are exceptions to the rule, for I have carried up stacks of very small height between high buildings, and have found the best effect follow. We have very little scientific knowledge as to this point, particularly with reference to the effect of wind.

Since heated currents always strive to ascend, and horizontal flues and angles present resistance to their

[58] That, however, a good draft may, even in such cases, be obtained by a moderate height of chimney, is exemplified in steam vessels.

motion, it is easy to understand the first two of these propositions. Laboratory furnaces show us that when we have only ascending currents, no high chimney is necessary to insure a good draft. I have in my practice never built high stacks, sometimes scarcely 25 feet, and yet the draft has never failed, but rather been very lively. The activity of the combustion depends in reality not so much upon the height of the column of heated air ascending the chimney, as upon the proportion the area of the last flue leading into the chimney bears to the size of the opening formed by the interstices between the furnace bars. The nearer these approach to equality, the livelier the draft.[59] I would often have built my chimneys less than 25 feet high, had it not been from the proximity of neighbouring buildings and the fear of adverse effect from the winds. Chimneys of 80 to 100 feet, particularly in a roomy situation, are useless superfluities, involving the proprietors in unpardonable expense, and manifesting a want of experience in their contrivance, if the only object proposed to be attained by them is improvement of the draft. There are, however, other motives for such a measure; the principal of which is to avoid annoyance to the neighbourhood by smoke, an offence against the laws of many States. A height of less than 70 feet is enough for such a purpose.

These laws regarding the nuisance of smoke from steam engines are both unjust and impolitic. Many other cases where coal is burnt, particularly smithies and iron works, are treated with less strictness, and indeed often passed

[59] 'Bull. de la Soc. d'encouragement pour l'Ind. nat.' June, 1833, page 179. [That is, the area of the flue should *not be less* than the sum of the interstices between the bars.—Tr.]

over altogether. Why such obstacles should be thrown in the way of the steam engine is to me incomprehensible. We acknowledge that England has attained her present high grade of industrial culture by her steam engines;—we complain often of continental inferiority in this particular; and yet we put a drag on our progression, lose sight of great and important objects through trivial considerations, and find that, from the highest quarters, where progression ought to be gladly encouraged, laws emanate which make advancement in science more shunned than promoted, and viewed with as much fear as reform in the political sphere. We are ever accustomed to attend more to a partial cry than to the voice of a universal need. We attach more importance to a little coal vapour than to that much higher and more glorious object, the power which the coal puts in our possession; and in order not to offend the noses or soil the linen of a few, we thwart the good of the many by endangering their highest interests. How would it fare with England if a little smoke brought about there such obstructions as it does in Germany? The English continue to live among their smoke, and find themselves well off in it too; they neither turn up their noses nor get asthma, but they live, and live long; for this smoke is the fruit of activity, and activity maintains the health and lengthens the life of man.[60]

131. It appears that the height of the chimney neces-

[60] I have retained this paragraph on account of its force and good sense, although more adapted to the Author's country than ours. It cannot be denied, however, that the presence of smoke is an evil; it is an evidence of imperfect combustion, and ought to be prevented as much as possible.—Tr.

sary for a good and regular draft may be considerably diminished when it is given a small area. The ordinary steam boiler chimneys have frequently a diameter at their lower end of 3 to 4 feet in the clear, diminishing gradually as they ascend. Such dimensions are excessive. In order to heat properly the monstrous column of air in such shafts, it is requisite that the current passing into them from the furnace must possess a very considerable temperature; and on this ground it is intelligible why some authors give a temperature of 500° Cent. as necessary for this purpose, and why the draft often diminishes in chimneys of a greater height than 100 feet, if the heat is not sufficient. Besides, the friction of the air column against the sides of the chimney should not be forgotten; it brings a considerable resistance into account, which is greater as the chimney is higher. With narrow chimneys, the heated column possesses much less bulk, and is therefore warmed to a sufficient extent with a much smaller expenditure of fuel. The objection to too narrow chimneys is their greater liability to get foul, and requiring more frequent cleaning.[61] A satisfactory rule for the height and breadth can only be given according to circumstances. I allow usually for every 6 square feet of surface of fire-grate, 1 square foot of sectional area for the chimney, giving, however, to the smallest never less than 8 inches square.

132. Turning now to the internal construction of the furnace, we begin with the *ash-pit*. This is certainly a very simple matter, but I have nevertheless something to

[61] The necessity of frequent cleaning may often be dispensed with by making a fire of shavings in the bottom of the chimney, by which the soot will be burnt out. A small door should be provided for the purpose.

remark upon it. It is often made too low. The ashes then collect in it quickly, and impede the proper supply of air, as well as cause destruction of the fire-bars by the heat. A height of 18 inches to 2 feet appears the most suitable; the fire-grate then stands at a convenient height for the stoker. The ashes should be cleared away as often as possible.

M. Köchlin recommends that a water-pan should be laid under the grate at the bottom of the ash-pit, and states his experience that the bars have been longer preserved thereby. He explains that the water is evaporated, and that the vapour mixing with the air as it passes into the furnace, prevents an overheating and destruction of the bars. Whether this explanation is satisfactory, I do not decide; it would rather appear that the vapour would be decomposed, and, by oxydating the bars, contribute to their destruction. If, however, the fact holds true, it is worthy of consideration. Such a water vessel would serve to extinguish the falling ashes, and prevent any danger of fire when they were carried away; it would, however, often so far spoil cinders and unconsumed fuel falling through from a coal fire, as to prevent their being used again, and would thus cause considerable waste of fuel.

Under some circumstances, the use of a *register* in the ash-pit is advantageous, especially where it is considered desirable that the engine should be self-regulating. Such a regulator is more easily moved than the common damper in the flues, which soon becomes so dirtied with the soot or damaged by the heat as to lose its mobility. In order that a register may be effective, the ash-pit must be closed in front with a door made to fit as nearly air-tight as possible, which may serve for the removal

of the ashes, while the register remains undisturbed. In order still further to insure the perfect action of this machine, it should be placed on one of the longest sides of the furnace, and in a place where it is not liable to be disturbed, or damaged by heat or rust. A channel may be formed in the brick-work to conduct the air from this to the ash-pit, taking care, however, to dispose it so that no ashes may collect in it. The register should have a square iron frame, in which it must be so suspended as to move with great facility, and to retain its free action.

133. With regard to the *fire-grate*, one of the most indispensable conditions is, that it be built in proper fire-proof masonry. Common brick-work is altogether unsuitable for this purpose for obvious reasons.

A great mistake is often committed in making the fire-bars too strong, and the interstices between them too small, which hinders a proper supply of air to the fire. We shall not err in making the bars $1\frac{1}{2}$ inch wide. In order to give them the necessary strength, they should have elliptic ribs projecting on their under side, to a depth of about 4 or 5 inches, dependent on the length of the bars: the rib should taper sharply on both sides like a comb, which will not only facilitate the penetration of air into the fire, but also allow conveniently the introduction of an instrument to clean out the interstices between the bars when they become stopped up with dirt or cinders. If the bars are long, it is advisable to cast lateral projections $\frac{1}{4}$ inch wide in the middle of the bar, which may butt against each other when the bars are in their place, and prevent lateral bending. When the grate is required of considerable length, as 6 or 8 feet, the bars

should be in two lengths, with a strong cast iron bearer in the middle of the furnace, so supported as not to bend.

Various rules have been laid down for the size of the interstices between the fire-bars; my experience, however, has given me the universal rule to make them under all circumstances half an inch wide. This width answers for all kinds of fuel, allowing but little to fall through, does not become easily stopped up, and admits conveniently of the introduction of the cleaning instrument.

A good kind of bar is that with a concave upper surface; I have found that it really deserves the good character it generally bears. The concavity becomes filled with ashes, which, conducting heat badly, prevent the too rapid destruction of the bar by the fire. The best material for furnace-bars is cast iron;[62] it is firmer, stronger, more durable, and cheaper than wrought iron, which soon becomes bent and destroyed. Bars of square wrought iron, laid with an angle upwards, are the worst of all. Hollow bars, through which water from the boiler flows, have been recommended, but do not answer. They are not durable, besides being productive of endless trouble.

I have already spoken (Art. 70) of the magnitude of the fire-grate, often made much too large, and have given rules for the dimensions corresponding to the power of the engine. According to my experience the description of fuel used has little or no effect upon the requisite dimensions of the grate.

With my first-described boiler, especially if large, it is desirable to keep the grate wide enough to equalize the heat over the whole of the tubes: this is indispensable for the regularity of the evaporation and the du-

[62] Provided, of course, that the heat is not great enough to melt them.—Tr.

rability of the boiler: irregular firing produces injurious unequal expansion.

134. Many different opinions are held as to what is the best distance to allow between the fire-grate and the boiler. All, however, agree that with coal for fuel this distance must be less than for wood or turf. It seems to me that the matter is much simpler than is generally supposed. According to my view the burning material itself, that is, its *uppermost* burning surface, should in all cases be equally distant from the boiler; whence the greater or less distance of the bars depends only on the weight and form of the fuel. If one kind of fuel has less weight, or developes proportionately to its weight less heat, than others, or is only obtained in large pieces, it must be laid upon the furnace in a thicker layer, and will thereby require a deeper furnace, than another kind which has less volume and more heating power. Therefore wood and turf require a thicker stratum than coal.[63]

In the arrangement of my fire-places I adopt the following rules.

(*a.*) For coal, I lay the fire-grate 16 or at most 18 inches under the lowest surface of the boiler.

(*b.*) For wood or good turf, I make it 6 inches deeper.

(*c.*) For light inferior turf, having but small heating power, I lay it 12 inches deeper, or even sometimes more, if the turf is very poor.

These rules have been established by experience as

[63] Good wood and turf do not, weight for weight, stand so much behind coal in calorific power as is generally believed. Many kinds of wood even exceed coal.

perfectly satisfactory, and are founded on the principles I have above laid down, against which I know no reasonable objection.

135. The best way to insure a regular method of firing, which shall be properly adapted to the requirements of the engine, shall produce least smoke, and shall most tend to the saving of fuel, is to employ a good and careful stoker. No ingenious mechanical arrangement—no scientific apparatus—can supply his place, be it ever so approved or scientific in principle, or perfect in execution. A good fireman can, however, only be retained by preventing his occupation from becoming too easy and simple for him, and by thus keeping his watchfulness and care in constant action and salutary exercise. The less exertion such men generally have to make, and the more convenient their occupation is for them, the more careless and inattentive they have a tendency to become; and, at last, nothing, not even their own danger, can awaken them out of their lethargy. All machines for feeding, smoke-burning, and the like, only increase the quantity of apparatus about a steam engine in an unnecessary and prejudicial degree, and withal augment the derangement and danger which ensue when they fall into disorder. The simpler an engine is built, the simpler is its management. The delusion of attempting to simplify its action by new scientific apparatus, which require new knowledge and new watchfulness on the part of the attendant, is one of the wildest that could be imagined, and inevitably sooner or later brings its own punishment. It is an attempt to get over one difficulty by introducing many new ones, often greater than the former. The

writer had on one occasion an ingenious machine of excellent construction attached to the boiler of an engine for the purpose of regulating the draft, and was much pleased with its secure and convenient action; but it soon had the effect of making the attendant become idle and careless, not only with the management of the fire, but of the engine also. At last he neglected the instrument itself, which had been of so much convenience to him, and the proprietor was glad to remove it again; for instead of regularity in the heating of the boiler it brought disorder, and where it was hoped to spare trouble and care, a double amount became necessary.

Those who wish to study smoke-burning contrivances, furnace-feeding machines, and the like, may find a rich collection of them in various publications.[64] I pass them all over, for I can say nothing further of them than this: the furnace-feeders are all complicated and expensive machines, working in great heat, easily destroyed, and constantly liable to get out of repair; while the smoke-burning apparatus have all this one important failing,—*they do not answer their purpose.*[65]

[64] Such as Dingler's 'Polytechnisches Journal;' Bernouilli's 'Dampfmaschinenlehre;' Prechtl's 'Technologisches Encyclopädie;' Gill's 'Technical Repository;' the 'Mechanic's Magazine;' the 'Repertory of Arts;' the 'London Journal;' the 'Repertory of Patent Inventions;' the 'Register of Arts and Sciences;' the 'Bulletin de Mulhausen,' &c. M. Prechtl, Director of the Polytechnic Institution in Vienna, has given in the sixth volume of the *Jahrbuch* of this Institute, p. 197, a most scientific treatise on smoke, the conditions of its generation, its removal, &c.; a work which I cannot too strongly recommend.

[The Author gives a long list of nearly forty contrivances of the above kind, with complete references, which I have not thought it necessary to copy. It shows, however, his amazing research, and the trouble he has taken to become acquainted with what has been done, and thereby adds weight to his opinions.—Tr.]

[65] Almost all arrangements of such smoke-burning furnaces act on the

A practice has sometimes been followed of moistening coal before it is put on the grate. Such a custom is so obviously bad, that it is unnecessary to say more upon it.

A Mr. Iveson in Scotland has lately recommended a very simple means of destroying smoke, and strengthening the heat in the furnace, by introducing a small current of steam upon the burning fire. According to the showing of the inventor, corroborated by the testimony of the celebrated chemist Dr. Fyfe, the saving of fuel amounts to one-half, and the smoke perfectly disappears. This plan, if it could be trusted to, would be especially applicable to high-pressure engines: it is, however, yet too little sanctioned by experience to command a favourable opinion.[66]

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principle of introducing fresh air to the fire current in the neighbourhood of the bridge, through openings furnished with registers, in order to regulate the quantity of air admitted. Now since this influx of air must always bear a certain definite relation to the action of the combustive process, the quantity of fuel on the grate, and the temperature of the fire current, it is evident that the regulation must be attended with the greatest, if not insurmountable, difficulties, and cannot reasonably be expected from a common stoker.

As I once visited the New River Water-Works in London, the stoker of a large pumping engine showed me a method by which, as I then saw and often since have proved, the smoke was very much diminished. After he had spread the fresh fuel as regularly as possible, and in a thin layer over the fire, he did not quite close the fire-door, but left a very small chink for the admission of air, which he closed tight as soon as the fuel was properly burnt through. He performed this operation every time with great exactness and calculated punctuality,—a circumstance imitated by few of his station. I have never met with a man of the kind who took so much interest in his business, and possessed so much intellectual activity as this man. I have to thank him for much information concerning English steam engines, especially the great water-work engines of London. [The plan here mentioned is by no means new or uncommon: the punctuality, attention, and intelligence of the stoker, are unfortunately more rare.—Tr.]

[66] An opponent of this plan states ('Mechanic's Magazine,' No. 854) that this, like other smoke-burning apparatus, does not destroy the smoke, but merely deposits it as soot inside the furnace and chimney.

136. I now pass on to the consideration of the *flues*. The opinion has frequently been held, that a long traction of the heated current round the boiler has important advantages. A late writer has, however, much shaken this opinion, if not proved entirely the contrary.[67] It is beyond all doubt that very long flues are disadvantageous, especially when horizontal. The cross area of them must be very large, and the chimney high, in order to produce a proper draft. A large area has the disadvantage that the current is imperfectly brought in contact with the sides of the boiler, and this is especially so when these sides stand in a vertical position, as in the side flues of the common Boulton and Watt waggon boiler, the heat having but little tendency to communicate itself sideways.[68] Long horizontal flues produce great inconvenience: on lighting the fire in a newly built furnace, much trouble is often required to drive out the damp, cold, heavy air produced from the wet masonry, which often impedes the draft so long as to lead to a belief that something is wrong in the construction, when no hindrance but this really stands in the way. I have sometimes surmounted the difficulty by making a fire in the chimney, but more frequently have been obliged to take recourse to more powerful means, such as applying a blowing apparatus to the ash-pit, and creating a strong blazing wood fire in the grate. With descending flues this disadvantage is still greater.

In my boilers the heat acts very little sideways; in the first kind all the flues lie beneath the tubes or cylin-

[67] Ed. Köchlin, 'Bull. de la Soc. ind. de Mulhausen,' No. 2.

[68] The sides of waggon boilers are frequently curved outwards at the top, to meet, in a certain degree, this objection.—Tr.

ders; and though they run horizontally, they do not, as is the case with the ordinary waggon boiler, all lie on one and the same level, but ascend gradually upwards. The most perfect plan is to avoid all long flues, and allow the heated current, during its ascent, always to act perpendicularly against the surface to be heated, and this is the plan I have adopted in my larger description of boiler.

With respect to the construction of the flues, it is essential that they be made even and smooth over the whole of their inner surface, to diminish the friction of the current along their sides. It is desirable also to avoid sharp bends, which cause eddies: in these places the flues should be given, where possible, a greater width, and all corners should be rounded. When wood or turf is burnt, which deposit light ashes in the flues, these must be made so wide as to allow the ashes to accumulate to a certain extent without so much stopping the area as to impede the draft. Suitable preparation must be made for the cleaning of the flues, by providing them with openings, through which the interior may be accessible, and which should be closed during the action of the boiler by cast iron stoppers, furnished with handles, and made air-tight by loam: these are better than doors, which never shut so securely as not to admit cold air.[69]

The form of the flues is regulated in most cases by that of the boiler, or rather of the surface to be heated.

[69] A very good door, suitable for such purposes, has been patented by Mr. John Sylvester, of London. It is exceedingly simple in construction; shuts perfectly air-tight without latches or other fastenings; and is not liable to deterioration from dirt or wear. It may also be applied to fire-doors, and has then an arrangement by which it is effectually protected from the heat of the fire.—Tr.

The section is usually either a square, or more frequently an oblong rectangle. Wherever possible, the form should be so arranged that the heated current may be made to impinge in the greatest degree upon the surface to be heated. To attain this end, what are called *dams* have been recommended to be placed in the flues; *i. e.* small projecting tongues, over whose oblique surfaces the current glides and is thereby guided anew against the boiler. All similar arrangements, however, impede more or less the draft, and require higher chimneys. When tubes lie in the flues, as in my smaller kind of boiler, the area must be contracted in the upper part round the tubes, in order to constrain the current to act upon their under sides.

Various rules have been proposed for the size of the flues. The principal one is to give in general a greater area to the horizontal than the vertical ones: this follows from the nature of the case, and from the principles I have above laid down. I adopt very simple rules for the furnaces of my boilers, which always fulfil the required conditions. They will be clearly explained in the description of the furnace.

The current passing from the flues is usually collected into one opening or channel, by which it enters the chimney; the area of this channel I always make equal to the sum of the interstices between the furnace-bars. In this the damper is placed; it is generally a simple cast iron slide, moving up and down in a frame let in the masonry. Such instruments have great defects, principally that they so soon suffer by the heat and the soot, and lose their freedom of motion. A better contrivance would be a plate swinging on a centre axis, fixed to a

frame, the axis projecting out, and being furnished with a handle by which the damper could be moved. This would act more freely, and be less impeded by dirt. The frame of the register ought nowhere to project beyond the interior surface of the flue.[70]

137. It is a question often mooted, whether small fire-grates, with a quick draft, have an advantage over larger ones in which the draft is more moderate.

Some engineers, and writers on the steam engine, assert that a strong draft is an indispensable requisite for high-pressure boilers, in order to generate steam of high temperature; and this is made an objection to the high-pressure system. The assertion, however, is contradicted both by theory and experience; for the temperature is not so much higher as to require such extraordinary means, and all who have had much to do with high-pressure engines will know well that with sufficient heating surface, a moderate draft answers perfectly.[71]

The question of slow and quick drafts does not seem to be attended with any great difficulty, if no peculiar circumstances enter into the consideration. Every kind of fuel burns more perfectly and with less smoke when it is supplied with the quantity of air proper for its combustion. With a sharp draft and strong fire, the bars, boiler, and furnace become sooner destroyed than with a more moderate combustion. Some kinds of coal will not bear a sharp

[70] Here follow some remarks on certain proposed boilers with vertical tubes, which, however, I omit, as the said boilers are neither known, nor likely to be known, in England.—Tr.

[71] This objection has arisen from the blunder of proportioning the boiler to the cylinder by the same ratio as in low-pressure engines, and thereby allowing too little heating surface. See Art. 69.—Tr.

draft, since with too much heat they fall to slack, and stop up the bars; and lastly, a fierce fire requires very frequent supplies of fuel, and clearing of the grate. But every time the fire-door is opened a stream of cold air enters, and so destroys a great part of the advantage gained. I am of opinion that the question can only be answered conditionally. With wood and turf, the draft may be tolerably sharp without disadvantage; while with some kinds of coal it should be regulated with much prudence. I would therefore advise that the boiler and furnace for high-pressure engines should have the power of a sharp draft, but should be able to supply steam enough with a more moderate one. There is at least then room to try how the fuel at hand may best be used. Too sharp a draft is easily moderated, while a weak one is not so easily increased, when its weakness arises from defect in the general arrangement. This plan will be found of advantage when, as frequently happens, in spite of all calculations and pains-taking in the construction, the draft is more sluggish than was expected. The golden rule, in the construction of a steam engine, *to do rather too much than too little*, holds good here: the purchaser will never find fault with the maker for its performing more than was promised, but woe to him if it performs less.

The principle of slow combustion has lately been carried to excess. In some of the large Cornish engines, the slow-burning principle has been adopted to such an extent that flame and smoke came out of the fire-door.[72] For my part, I must confess that I consider the whole thing, when carried to this extreme, as a retrograde step; for theory and practice show that coal

[72] 'Civil Engineer and Architect's Journal,' Jan. 1840.

of every kind always gives out much smoke by a repressed draft, and no combustion can be favourable which sends a great quantity of consumable matter away into the chimney. Time will decide whether in this, as in most other things, the golden mean is not the best. I at least have always found it so.[73]

138. The fire-doors used for steam boilers are often very ill adapted to their purpose. Their position is sometimes inconvenient for the stoker; they lie either too high or too low; shut badly; are not well protected from the action of the fire; or cannot be opened by the hand without burning. The most important faults are their not shutting tight, and the existence of openings in them, sometimes intentionally made for the purpose of looking in at the fire. The whole supply of air ought to pass through the bars and the fire itself, in order to produce the best possible result, in reference to the perfect combustion of the fuel and the proper application of the heat; and all cold air entering elsewhere can only disturb the regular action of the process, and produce mischief. The leaking of the doors is usually occasioned by their warping through the great heat: the best way to avoid this evil is to provide the door on the inside with a cast iron box filled with ashes, or a strong plate supported by four or five props at a distance of 2 inches from the door itself, in order to protect it from the action of the fire. As for the peep-openings, they should either be provided with a falling cover, or, which is better, abolished altogether. The door should be placed

[73] The Author's proportions give a consumption of about 7 to 10 lbs. of coal per square foot of grate per hour. This is a medium between Boulton and Watt's (12 to 16) and the Cornish (3 to 4) rate of combustion.—Tr.

at a convenient height for the stoker, not for convenience alone, but also to insure a regular distribution of the fuel over the grate. The opening should be on this account tolerably wide. The door should be provided with a wood handle, that it may be opened by hand without burning the fingers.

Many persons use, instead of hinged, sliding doors, moving up and down in guides, and suspended by a chain with a counterweight. These are objectionable, because they do not close tight, and cannot be protected from the action of the fire in the manner hereinbefore mentioned.[74]

DESCRIPTION OF THE AUTHOR'S FURNACES.

139. I come now to the description of my own furnaces, commencing with that of my *smaller boiler*.

This is shown in Plates I. II. and III.; as arranged for three pairs of cylinders, sufficing for 6 horse-power. Figs. 1 and 2 are the side and front elevations; fig. 3, a longitudinal section; fig. 4, a transverse section on the dotted line *d d*, fig. 3; fig. 5, a similar one on the line *e e*. The scale will give the dimensions of the several parts: *g*, in figs. 2, 3, 4, is the ash-pit, open in front, and arched over with fire masonry: this is covered with the cast iron furnace plate *i*, figs. 2 and 3, which contains the fire-door *k*, hanging by strong hinges, and having its latch *l* provided with a wooden handle *m*. At the back of the door is either a box filled with ashes, or, as represented in fig. 3, a false plate *n*, supported on props, to protect the door from the action of the fire. This contrivance must be so constructed as to be easily renewed when it is burnt away. The large front furnace plate, which is hol-

[74] See note to Art. 136.—TR.

lowed out at *r r*, fig. 2, to receive the tubes, rests firmly with its lower edge upon the masonry at *s*, and is secured by four strong bolts *t t*, which run through the furnace from back to front, and serve also as cramps for the furnace itself, being screwed up to strong washer plates at the back end. The plate *i* is strengthened by ribs in different directions, which ornament its front surface.

The internal construction of the furnace is shown clearly in the several sections, namely, figs. 3, 4, 5, and 6.

At 9, 10, fig. 3, lie the cast iron bearers for the furnace-bars; the front one rests upon the arch over the ash-pit, the other upon the wall at the back. The bars, marked 11 in the figures, lie in all cases horizontally, and not, as is very common, inclined downwards towards the back end: their form and dimensions may be learned from the figures. When the fire-door is not so wide as the grate, two piers are built at the sides, of fire-proof masonry, 6 inches thick, which carry the flat arch *h*, fig. 3, also of fire-brick, over the door. The dead plate between the grate and the door is in one piece with the front bearer.[75] The grate cannot always be so wide as the space above it required for the tubes, and in this case the side walls are made to widen out upwards in the manner shown in fig. 4, where these oblique walls are marked 13. Their angle with the fire-grate should, however, never be more obtuse than 110°. All this work must be fire-proof.

If the tubes require a great breadth, it is well to make

[75] The expansion of the bars often causes trouble unless room is allowed for it: it is no uncommon thing to see furnaces cracked and much damaged by this cause. Several expedients, well known to engineers, are adopted to give the ends of the bars a little play.—Tr.

more than one fire-place: this arrangement has the great advantage that some fires continue burning undisturbed while others are being supplied with fuel; and if the firing is done in turns at regular intervals, it will much contribute to the regularity of the evaporation. One fire-place will not serve well for more than three pairs of tubes.

Each of the lower cylinders lies in a separate channel, 11 inches wide and 13 inches high. A space of 5 inches is left under the cylinder, which is more than sufficient for the draft, but provides also for the accumulation of ashes and dirt. The division walls, for channels of this size, are about 4 inches thick, built of fire-brick, and serve to support the covering of the channels. The cylinders must lie perfectly free, so that the flame may also act on their upper surfaces; and therefore the covering, though it may touch, must not be fixed upon the top of the cylinder. As the lower cylinders are always entirely filled with water, and the steam generated is also mixed with water, there is no danger of their being damaged by over-heating, as experience has proved. About 8 inches from the back end of the flues, the division walls, together with their covering, end, since here the heated current passes between the tubes, in order to arrive at the flue running along the upper cylinders.

The front and back walls of the furnace are made only 6 inches thick in the neighbourhood of the flues, in order to give as much effective length of cylinder as possible. This thickness is quite strong enough to support the cylinder ends, and give the furnace the requisite solidity.

At the back end of the lower flues is a small sunk cavity, opening outwards under the back end of the

cylinder. This is marked 11 in fig. 3. Its use is to afford facility for cleaning the flues. It must be closed, when the boiler is in action, by a cast iron or brick stopper, luted air-tight in the opening. There are also openings under the upper cylinders, for the purpose of sweeping the upper flue.

The flue in which the upper cylinders lie need have no division walls. I at first thought these would be an improvement, but further experience convinced me of the contrary. The tubes themselves form the upper part of the flue, and are therefore in the most favourable position possible. When, however, more than one fire-place is used, the flues of each must be separated from those of the others; each being, so to speak, an independent furnace of itself. The upper flue is made deep enough to allow room for the collection of dirt and ashes, and as the heat tends upwards, this is no disadvantage. The cover of the lower flues forms the floor of the upper ones; it consists of fire-bricks laid flat, and covered with a layer of tiles, so as to break the joints; the whole set tight in fire-clay. The upper half of the higher cylinders is covered with brick-work, so that the flame cannot act on that part which is appropriated to the steam room. Fig. 5 shows these arrangements so clearly as to need no further explanation.

The current passes along the upper flue from back to front, where it is led upwards through the interstices (*h h*, fig. 4,) between the cylinders, into the cross flue *u u*, in order to pass into the chimney. In this place the upper part or steam room of the cylinders must be protected from the heat by bent plates, under which is placed a layer of loam mixed with cow-hair. This

covering should extend downwards 1 inch lower than the centre of the tube, and be contracted round it at the lower part, in order not to diminish too much the passage way between the cylinders. This arrangement is shown at *v*, *v*, *v*, fig. 4. The sum of the areas of the passages between the cylinders should be at least two-thirds of that of the interstices between the furnace-bars, and this will be accomplished by giving them a length of 12 to 14 inches and a breadth of 4 inches. The breadth of the flue *u u*, should be equal to the length of the opening *h*, and its section should be square: it is disadvantageous to have it too small, as the current must make a sharp turn, and ought to have plenty of room.[76] The walls and cover of this flue need not be thicker than 6 inches. One end is furnished with a cleaning opening *i*, and in the other is placed the damper *v′*, fig. 4. I have before remarked that the area of the damper opening must be equal to the sum of the interstices between the fire-bars. The damper must be of cast iron, and slide in a frame of the same material, which must be securely set in the masonry. See Art. 136 for other remarks on this part of the apparatus.

It is indispensably necessary to secure the masonry of the furnace properly with cramps, that it may not be cracked or disarranged by the heat. These cramps must be placed in the direction both of the length and the breadth of the furnace, projecting with screwed ends out

[76] I found this particularly in a boiler I put up at Rostock: the flue was originally only 8 inches high, and the draft very bad; but on increasing the height 4 inches, it became so powerful as to produce a roar that might be heard 400 paces away. There were two fire-places, with 7 feet of grate, and five pairs of cylinders, the upper ones 9, the lower ones 7 inches in diameter. The chimney was 1 foot square.

of the masonry, and being screwed with strong nuts and washer plates against it. It is very advisable to surround the whole of the upper edges of the furnace with an iron frame, to protect them from injury.

The top of the furnace should be covered with a layer of tiles, to prevent radiation; or, which answers the purpose better, the tiles may be laid hollow, leaving an air space between them and the top of the brick-work.

140. One of the side walls of the furnace is usually built against the chimney or the wall of the building; the other is then free, and when a self-regulating ash-pit register is required, it may be placed on this side, as I have shown in fig. 1. *w*, figs. 1 and 4, is a channel leading to the ash-pit, in the outer opening of which is placed the moveable register. This has a small lever arm *x* attached to it, connected with the regulating-rod *y*. This rod is again attached at *z* to a lever (1) working upon a gudgeon (2) fixed to the masonry, and pressing with its other end against the piston of a small cylinder (3), whose upper part communicates by the copper tube (4) with the steam-pipe, that the piston may receive a pressure on its upper side equal to that in the boiler. The piston is packed by a greased leather cap, fastened by a screw, and protected from the action of the steam by the tube having its descending leg filled with water, which will remain cool for a long time. The diameter of the cylinder need seldom be greater than one inch, even for large engines, as the register requires but little power to move it. On the long end of the lever is hung a weight (6) which holds the piston back in the cylinder with a certain force, determined

according to the pressure desired in the boiler. When the pressure exceeds this, the piston will be pressed down, the long end of the lever raised, and the register closed, thereby shutting off the supply of air from the fire. When the pressure is reduced below the given amount, the counterweight predominates, and the door is again opened. It is advantageous to place the whole of the apparatus, except the register, on a plate (marked in the figure), firmly secured to the furnace wall. It should also be partially covered, to protect it from derangement by blows, &c. The connection-pipe should be furnished with a stop-cock and union-joint, by which it may be disconnected when necessary. The small stop marked 8 is to prevent the piston from descending too low.

A pressure too great in the boiler is a sure sign that the production of steam is greater than its consumption, and that therefore the fire is too strong. This machine serves to regulate the fire, and also performs the function of a second safety apparatus, which brings not merely palliative relief, but goes to the root of the evil by removing its cause. It is tolerably sensitive, requiring only a few pounds above the given pressure to set it in action. The door should not be allowed entirely to close, which would be productive of mischief in the furnace, but should only shut off the air in such a degree as to diminish the intensity of the fire.

If it is desired to shut the register gradually, the altered form of the apparatus shown in Plate v. fig. 28, may be adopted. The lever *a* supplies the place of that marked (1) in fig. 1; one end is engaged with teeth into the piston-rod *b*, (supported by the roller *c*,) while

the other end, hanging down, is loaded with a weight whose effective force increases as it is raised. If the weight is properly calculated, the register will be gradually shut as the pressure in the boiler increases, and an exact regulation of the fire may thus be obtained. The place of the lever and weight might be supplied by a spring acting against the piston, and in either of these latter forms the apparatus would also serve for a pressure-gauge.[77]

141. The furnace of my larger description of boiler is exceedingly simple, containing properly only a single ascending flue, with no labyrinth-like convolutions, or disadvantageous bends or contractions. The heat ascends uninterruptedly through it, and when the chimney is favourably situated and properly built, the draft will scarcely ever be otherwise than strong.

The ash-pit and fire-place are of the ordinary construction. I always make the grate the entire length of that part of the tubes lying free in the furnace and acted upon by the heat. Its width is then regulated according to the quantity of surface required, which must be calculated by the given rules. With this boiler the grate receives the width of the space occupied by the tubes, since an addition to the number of tubes, when eight rows are used, stands in just proportion to the requisite extension of the fire-grate surface, in the direction of its width. I usually place a large cast iron plate in front

[77] Of course it is understood that when this apparatus is used, the front of the ash-pit must have an air-tight door. I must remark, however, that such a gimcrack appears to me to come fully under the anathema of the Author (Art. 135) against furnace machines in general. No automaton regulator can be wanted when a good stoker is employed, and I believe the Author has never used any such apparatus as that alluded to.—Tr.

of the furnace of this boiler, in which the fire-doors are situated, and which, by a broad rib screwed on the back, serves as a support for the hearts. Figures 29, 30, 31, 32, will explain these arrangements without further description.

Over the grate is the heating chamber for the generating tubes: it is an oblong rectangular space, of such a height as to contain all the eight tiers of tubes, and to allow at least 6 inches space above them. The width should be such that the walls approach to within about $\frac{3}{4}$ or 1 inch of the exterior tubes on each side. The distance of the lower tubes from the grate is regulated according to the rules already given.

The furnace is closed in at the back of this heating chamber in a peculiar manner. Since the tubes must project out in such a manner that their ends lie perfectly free for cleaning, it would be scarcely possible to use masonry in the small space between them without robbing them of too much heating surface: I have therefore made the closure with cast iron plates of 1 inch thick, hollowed out at the top and bottom in the proper form for the tubes, and inserted gradually between them, as they are screwed into the hearts during the building of the furnace. The plates are made tight to each other and to the tubes by thin layers of loam and cow-hair, mixed with a little sal-ammoniac and iron filings. In fig. 51 several of such plates are represented, showing the recesses *a a*, hollowed out for the reception of the tubes, and the joints *b b*, between the plates themselves: the ends of the tubes project $\frac{1}{2}$ inch. The plates enter into grooves in the sides of the furnace, and rest upon its inner wall; the grooves are wider than the plates, to

allow of brick with loam being built in behind them after they are all fixed: this must be done so firmly as to hold them fast in their places, but yet so loosely as to be easily removed when necessary, for the purpose of taking out any of the tubes. In figs. 31 and 32 this groove is shown by dotted lines, and marked *o*. *p p* is the plate in section.[78]

q is the external continuation of the furnace wall; it extends on each side usually 18 inches outwards, and terminates at the top in an arch uniting the two sides so as to form a sort of niche, which contains the projecting ends of the tubes, and must be closed externally by a cast iron door shutting as tight as possible. The sheet of air between this and the tube plate tends to prevent loss of heat from the outer surface. Fig. 32 explains this. *q q* is the interior of the niche, *r* the bottom, *s* the arched covering, *t* the outer door.

It was a difficult problem with this boiler how to direct the heat through the interstices between the tubes, so that it should distribute itself equably upon all sides, and not take any partial direction, acting more powerfully at front, or back, or more on one side than the other: such unequal action would be injurious to the structure of the boiler as well as prejudicial to its favourable working. In order to accomplish this I have, in the first place, made the bars the whole length of that part of the tubes lying in the furnace; and secondly, I have covered the heating chamber with a cast iron plate, lying 4 or 5 inches above the upper tubes, and provided

[78] This plate seems much exposed to destruction by the heat: in England it could be formed of burnt fire-pottery, of which articles of all sorts of shapes are now made, possessing very considerable strength.—Tr.

with rows of oblong rectangular openings, through which the heated current streams. The plate is shown at *u u* in figs. 31 and 32, where the position of the openings will be clearly seen. They are in as many rows as there are tubes in the upper row, and are placed exactly over the tubes, in order that the current may be compelled to encircle them as much as possible before it passes away. The sum of all these openings I make equal to $\frac{2}{3}$rds that of the interstices between the fire-bars. The current is compelled to pass simultaneously through all the openings of the plate, in order to obtain room enough to pass away, and thereby becomes equally spread over all the heating chamber. Experience has proved the efficacy of these means. The plate is not liable to be burnt away, since it is acted upon by that portion of the current from which the heat has in great measure been extracted.[79]

I have now briefly to show how the heat acts upon the tubes in the heating chamber. I have already remarked that many engineers, and in particular Seguier and Stephenson, have observed the fact that currents of heat which strike perpendicularly upon the heating surfaces of a boiler, act much more powerfully than those which travel parallel to its sides. In the former case the current suffers a kind of damming up, or concentration, and acquires a whirling motion that produces an equable distribution of the temperature, and brings constantly new heated strata in contact with the surface. The general laws of reverberation apply here; the current, during its passage between the tubes, is reverberated from one against another, parting with more and more

[79] This might also be made of fire-pottery with advantage.—Tr.

of its heat at every turning, until, on arriving at the uppermost row of tubes, its temperature may be possibly reduced near to the limit of further communication of heat, *i. e.* to the temperature of the boiler itself. This perfect abstraction of heat is the more possible since the whole current is retained among and around the tubes themselves, with the exception of that portion which passes by the sides of the furnace, and this is very small in proportion to the whole. The alternating position of the tubes which I have chosen is very important. When they are placed in perpendicular lines over each other, the current will always pass in preference up the space between them, without encircling them, which it is essential it should do. It is astonishing how little this circumstance appears to have been attended to by contrivers of tubular boilers. It certainly has caused me the highest surprise that the plan I have described for heating tubes has not been generally made use of at an earlier period. Traces of it are found in some air-heating apparatus and in a few boilers, but little weight seems to have been attached to it, otherwise it would have been more zealously prosecuted. Ever since I have occupied myself with experiments upon steam boilers, the importance of this manner of leading the heat against evaporating vessels has presented itself to me, and I have unintermittingly striven to bring it to perfection. The result has justified my views as to its advantages, and therefore I recommend it to the further researches of my companions in science.

The proportion of the heating surface of the tubes to the surface of the walls enclosing the heating chamber, is particularly favourable in this boiler. In the ordinary

waggon and cylindrical boilers, the latter often considerably exceeds the former; in mine the ratio is only as 1 to 3 or 4, and often in large boilers as 1 to 6. This explains why so little heat is lost from the furnace, and why the steam may be raised so quickly.[80] Large boilers so constructed have on this account considerable advantage over small ones.

It is not necessary to line the whole of the interior of the heating chamber with fire-proof masonry. I have found that half the height is sufficient, as above this the heat has so much lost its intensity as to do no damage.

It is remarkable that these boilers give as good results with a moderate draft as with a strong and intense fire. This is a considerable advantage on the score of durability.

The heated current, after passing through the plate over the heating chamber, may be carried off in any method most suitable according to circumstances. Where there is only one heart, it may pass upwards in a flue between the separator and the receiver, and be thence conveyed to the chimney. The best situation for the chimney is by the side of the furnace, as it does not then interfere with the room for cleaning; and when so placed, the current may pass directly into it by a flue under the separators, as shown in figs. 31 and 32. This plan can be adopted when there are several hearts; I have used it so in my own boilers, and found it succeed well, both fire-places having the draft perfectly equal. The masonry between the separators and receivers may be a flat arch leaning against the vessels themselves as abutments. In

[80] The boiling temperature is often reached in 20 or 25 minutes after lighting the fire.

the figures, *v* is the flue leading to the chimney, furnished with a damper *w*.

142. In conclusion of this part of my work I must remark, that it is in the highest degree disadvantageous to place the boiler and furnace in the same room with the engine. The boiler should always have a separate locality to itself, in order that the coal-dust and ashes, which are inevitably spread in the room by the firing, raking, &c., may not damage the working parts of the engine: these ought to be kept in the cleanest possible state, if they are to endure long without requiring repair. I always separate my engines most carefully from their boilers, and, where possible, I provide the door of communication between the two chambers with a self-acting arrangement to shut it when accidentally left open. I also, where circumstances will allow, fix a ventilating tube in the boiler-room, to carry off any vapour which may be present, and which would, if it reached the engine-room, fall on the polished parts and rust them. The more attention is paid to the elegance and cleanliness of the machine, the better will it work, and the longer will it endure. It is no superfluity to place a steam engine in a neat and well-ordered room, and to keep its parts in a polished and handsome condition; such care spares many expenses, and has at the same time the advantage of providing for the attendant a constant source of employment. Watchfulness, without settled material occupation, tires every one; and want of the latter often becomes the cause of absence of the former.

PART III.

ON THE ENGINE.

ON THE ENGINE.

143. I now come to the consideration of the engine itself, in the construction of which there is great room for improvement. I have already had occasion to remark (Art. 43) that it is a great mistake to confine our attention to the boiler alone, the application of the steam in the engine being a point to which we may look for the most important results, in the economical improvements of the high-pressure engine.

Before I enter on a complete and detailed description of my own plans, I will, following the system already adopted in the former parts of this work, offer some general considerations on the construction of the engine and its several parts, as usually made. The reader will thereby be enabled to judge to what points beneficial improvement ought most to be directed.

GENERAL PLAN OF THE ENGINE.

THE OSCILLATING CYLINDER.

144. I construct my engines generally with oscillating cylinders, making exceptions to the rule only in a few cases, where the locality or the object in view may require a different arrangement. It will easily be imagined that I have not adopted this form from any inconsiderate prejudice in its favour, but have had important grounds for my choice of a plan which has met with so much opposition. I have striven, not only to try the value of, but also to remove, the grounds of objection brought against the oscillating engine.

145. It was about the year 1821 that Aaron Manby first took out a patent for oscillating cylinders for steam engines,[1] but a long time elapsed before any attention was paid to his scheme;[2] and although it appears at

[1] In the year 1823 the same idea occurred to me, without knowing of Manby's plan.

[2] The Author gives some few historical particulars respecting the introduction of the oscillating engine into use; but as these are very imperfect, I have omitted them, and have endeavoured to supply a more correct history.

The idea of making the steam cylinder vibrate upon trunnions or centres, and attaching the piston-rod directly to the crank-pin, first sprung from the prolific brain of RICHARD TREVITHICK. In the specification of the patent granted March 24th, 1802, to Trevithick and Vivian, the patentees describe a vertical sugar-mill worked by an engine on this principle, in which not the cylinder only, but the boiler, fire-grate, and chimney, all swing together in one piece upon a vertical axis, in the position shown in fig. 102 of the present work. The claim, however, was not limited to this combination, as the following passage shows: "In such cases or constructions as may render it more desirable to *fix* the boiler with its chimney and other apparatus, and to place the cylinder out of the boiler, *the cylinder itself may be suspended* for the same purpose, upon trunnions or pivots in the same manner; *one or both of which trunnions or pivots may be perforated*, so as to admit the introduction and escape of the steam or its condensation, as before mentioned." One could scarcely wish a better general description of the oscillating engine of the present day.

Mr. Witty took out several patents, from 1810 to 1813, for engines with moveable cylinders; but it does not appear that either he or Trevithick ever put the invention in practice. The first oscillating engines actually made were constructed by Mr. Aaron Manby, of the Horseley Iron Works, Staffordshire, under a patent dated 9th May, 1821, in the specification of which he describes a pair of oscillating engines, working cranks at right angles to each other, and having one air-pump between them, precisely as used in steam vessels at the present time. Several of such engines were constructed and set to work by the patentee in conjunction with his son, Mr. Charles Manby, the present Secretary of the Institution of Civil Engineers: they worked some time, but in consequence of trouble with the valves, the plan was not immediately successful. It appears (by a memorandum now deposited in the Institution of Civil Engineers) that Mr. Manby at first intended to use the slide-valve; but fearing difficulty in the gearing, he abandoned that form, and introduced a kind of self-acting circular valve round the trunnion, which however, in practice, wore unequally, and could not be depended on.

present to be gradually spreading, yet it is still more or less opposed by the general opinion of mechanical engineers. It may in some instances have been objected to from unworthy motives on the part of manufacturers: I will not waste time upon these, but will proceed at once to examine those objections against the oscillating engine which have real weight in the balance of truth. Such are the following.

146. *First Objection.*—It is said, that to set so great a mass as a steam cylinder in motion, causes great concussions, and requires a considerable expenditure of power; since every time the motion is reversed, the inertia of the mass must be arrested, and an impulse

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The final important improvement, namely, the adaptation of the *slide-valve*, which made the oscillating engine a good working machine, was patented by Joseph Maudslay, 1st August, 1827. In a prospectus published at the time, the patentee remarks—

"Vibrating engines have not hitherto been successful for this reason, that from the difficulty in the application to them of some of the most vital parts of the best engines, these have been omitted, thereby causing not only a decrease in power, but also a considerable increase in the consumption of fuel. The difficulty, however, has been obviated in the 'Improved Vibrating Engine,' which combines all the essential parts of the most improved engines, and, with the same diameter of cylinder, is rendered equally effective, principally by the application of a D valve or slide, worked by an eccentric (not hitherto used in engines having vibrating cylinders), by means of which the steam is conveyed to and from the cylinder in the most economical and effective manner."

Two 10-horse engines on this plan were erected by Messrs. Maudslay and Field, in 1828, on board the *Endeavour*, a small boat built to ply between London and Richmond: she commenced running in May, 1829, and remained on the station till September, 1840. These may therefore be called the first successful oscillating engines. Several other boats were subsequently fitted with engines on the same plan, by this firm.

About ten years ago, Mr. Spiller, of Battersea, made some further improvements to the valves and gearing, and soon afterwards, the plan was zealously

given in a contrary direction. It is supposed that by this the cylinder, piston, and piston-rod receive injurious shocks and side strains, whereby the cylinder and the stuffing-box of the piston are caused to wear unequally.

This objection might apply to large low-pressure engines where the piston-rod was not well guided, and where the moving parts had great weight. I leave it however to be considered whether the objection might not be urged with greater force against the ordinary side-levers or beams, which are usually heavier than the cylinder, and move through a proportionately greater vibratory arc. The objection can have but little weight with the smaller and lighter cylinder of high-pressure engines, especially with mine, which swing like a pen-

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applied and brought into more general notice by Messrs. Penn, of Greenwich, who, by their careful and persevering attention to the details, gained for the oscillating engine a high degree of favour. It is now extensively manufactured on a large scale by several marine engineers, among whom Messrs. Rennie and Messrs. Miller and Ravenhill may be mentioned as having made some of the largest engines. Those of the *Pottinger*, *Ripon*, and *Indus*, constructed by the latter firm, have cylinders 76 inches in diameter, and a stroke of 7 feet, equal to between 400 and 500-horse power the pair.

The late general use of the oscillating or some other simple direct action engine, combined with the tubular boiler, and an increased pressure of steam, (all principles adopted and recommended by our Author,) on board steam vessels, has given the power of attaining a speed in the present day which, a few years ago, would have been deemed scarcely possible.

Readers of this work must bear in mind, that although the oscillating plan is now so much in favour, such was not the case when the book was written. The preference given to it by the Author is clearly the result of his own honest investigation, adopted in direct opposition to what, according to his knowledge, was the prevailing opinion at the time; and free from all suspicion of following in the wake of others: the present success and late general use of the plan greatly enhance the merit of the Author's choice, and furnish a testimony to the value of his opinions.—Tr.

dulum, and allow the power of gravity to act in checking the motion at the end of the vibration, and in giving an impulse in a contrary direction; so that the weight of the cylinder rather favours the motion than hinders it. There can scarcely be any mention of loss of power in such a case as this.[3]

As to the alleged rapid and unequal wear of the piston, rod, and stuffing-box, experience has shown this to be a matter too trifling, with cylinders of small dimensions, to deserve notice, and the parts which do become worn can easily be restored. The side thrust is much less than is usually supposed,[4] and the wear of the stuffing-box thereby is insignificant, when properly constructed. I have found the brass bushes, when made adjustable by alteration of their position, last six years, and when too much worn, they are easily and quickly replaced with

[3] It is a great mistake to imagine that, leaving friction out of the question, there is any *loss* of power, in the aggregate, in setting the cylinder of the oscillating engine (or a reciprocating part of any engine) in motion, or in bringing it to rest. The laws of mechanics teach us, that all the power which is expended in setting such masses in motion is restored by their coming to rest again. In all such cases the power requisite to give velocity is, so to speak, only lent, not thrown away. The stroke of the Cornish engine is an excellent instance of this. See 'Appendix G. to Tredgold,' Art. 174; Moseley's 'Mechanics of Engineering,' Art. 146.—Tr.

[4] This thrust depends principally on the friction of the trunnions, since the force requisite to move the cylinder (neglecting the effect of its weight and mass) is simply what is necessary to overcome this friction. Taking an engine of the dimensions shown in the Plates, and assuming the greatest pressure on the piston = 2000 lbs., and the co-efficient of friction $\frac{1}{10}$, the friction of the gudgeon will be = 200 lbs. The radius of the gudgeon is 2 inches, and the distance from its centre to the stuffing-box is about 40 inches, giving a leverage of 20 to 1. The side thrust, therefore, upon the stuffing-box will be about 10 lbs. It is found in practice that the wear in oscillating engines is not greater than is often caused by the want of truth of the parallel motion in beam engines.—Tr.

new ones. With larger cylinders it would be easy to adapt suitable guides for the piston-rod, but I have never found these necessary, even with engines of 30-horse power. I would make them of 50 or 60-horse, and am fully convinced they would compete in durability with beam engines, in which there is great danger of side thrust to the piston-rod, if the parallel motion is not kept in almost mathematical adjustment; a very difficult duty for ordinary engine attendants.

147. *Second Objection.*—It is thought by some that the piston, acting by its weight sometimes on one side of the cylinder, sometimes on the other, will produce unequal wear.

This again could only apply where the pistons were very large and heavy, and were provided with metal packings, the springs of which easily gave way. With hemp packing, the piston is too securely guided to be affected by a slight side pressure, and the deviation from the vertical is too insignificant to be worth considering; in my engines the angle never exceeds 12 degrees, seldom 11. Cylinders are now used even horizontally, notwithstanding the great outcry that was once raised against this position, on account of the supposed unequal wear.

148. *Third Objection.*—This is perhaps the most weighty of all, affecting, to the best of my knowledge, all oscillating engines as at present constructed, and justly so. It is, the great friction of the trunnions upon which the cylinder swings. This friction is greater than many persons suppose, on account of the high temperature

to which the trunnions are subject from the steam passing through them: with high-pressure steam the temperature reaches a point at which metals move upon each other with difficulty, and are subject to great attrition. As an example of the great increase of friction by heat, I will instance a common brass cock, which may be turned in its seat, when cold, with great ease; but under the heat of steam of 8 atmospheres, will stick so fast as to be scarcely moveable.

It must not however be imagined, that because I acknowledge the weight of this objection, I allow a triumph to the enemies of the oscillating cylinder; on the contrary, I hope thereby to show more clearly the advantage of the arrangement I adopt, which removes the objection altogether. It is incomprehensible to me that my plan has not been before tried and used, it is so obvious and so simple. Perhaps this is because the weight of the objection has been generally too lightly esteemed. Experimenters have contented themselves with ascertaining the friction between metal surfaces in a cold state, and have hastily drawn general conclusions from these, without experiments and observations on the much greater friction under heat. In this manner the most unheard-of mistakes have been committed. According to my experience, the friction between metals at a high temperature, particularly when under considerable pressure also, increases in an alarming degree. I have even found that the copious use of unguents diminishes it but little, and am therefore always inclined to avoid it, wherever it is possible. Unfortunately, machinery working under such circumstances cannot always be dispensed with in steam engines, and we must therefore regard these cases

as necessary evils, but must still strive to diminish them wherever we can. The instance under consideration is the most important of the kind, owing to the whole strain of the engine being thrown upon the cylinder trunnions. I shall hereafter show how I propose to get rid of the objection.

149. A *Fourth Objection* has been brought, that when the distance of the trunnion axis from the crank-shaft is too small, the vibrations are unequal, as is also the force transmitted to the machine. To which I answer, that there is no compulsion to make this distance too small; and that when it is suitably adapted, the objection applies to this case no more than to the ordinary connecting-rod.[5]

150. So much for the objections against the oscillating cylinder. I will now proceed, on the other hand, to examine the advantages of this arrangement, always having particular reference to the high-pressure engine.

First Advantage.—The oscillating cylinder simplifies the steam engine, particularly the high-pressure engine, in a very high degree. Against unnumbered scientific apparatus;—the massive beam; the parallelogram with its 18 or 20 joints; the colossal connecting-rod, and so forth;—the oscillating cylinder lays nothing in the scale, except two trunnions, with their bearings, and a single connecting piece between the piston-rod and the crank-pin; scarcely the thirtieth part of the former. An oscillating steam engine consists properly of nothing further than the cylinder, the crank, and the fly-wheel,

[5] Much abridged; the objection has no weight at all.—Tr.

between which parts in the beam engine the most elaborate, weighty, complicated, and expensive organs of the whole machine lie. Instead of a costly array of apparatus to convert the rectilinear into the circular motion, the crank is worked directly by the piston-rod. Can any thing more simple be imagined?

151. *Second Advantage.*—Oscillating engines, thus being more simple, require less trouble, labour, and time in their manufacture, and can be constructed in smaller and less perfectly arranged establishments than the old form; they require less expenditure in preparations, and fewer models. In my engines, as will be seen hereafter, the fitting is reduced as much as possible to the quickest and cheapest kind of work, namely, that which is done in the lathe: we have to do with scarcely any colossal and heavy parts, or, where these are made use of, they are as good as finished when they come out of the foundry; such, for example, are the framing and columns.

152. *Third Advantage.*—The oscillating engine has a more compact and compendious form, is more compressed, and requires very little space. It is therefore peculiarly well adapted to marine purposes, where there is usually but little room to spare.

153. *Fourth Advantage.*—The oscillating engine is much lighter than the common one.

154. *Fifth Advantage.*—It is more portable. An engine built by me at Güstrow may, with the exception of

the boiler and the fly wheel, be carried by two men, although it is of three-horse power, and often works to four and a half.

155. *Sixth Advantage.*—It is cheaper;—a circumstance of great importance to all who have to purchase steam engines.

156. *Seventh Advantage.* — The oscillating engine is more simple in management, and requires less care and knowledge on the part of the engine attendant. It has only the simplest kind of apparatus to be looked after. Its construction is founded on no scientific calculations unknown to the attendant: the connection and action of its parts, the combination of their motions, and their dependence on each other, lie so clear before the eye, that the least gifted capacity cannot fail quickly to understand them. I confide in most cases the care of my engines to ordinary workmen, and am content with their service. This cannot be said always of the ordinary low-pressure engine. What exactness is required, for example, to maintain the true adjustment of the parallel motion,—an apparatus so delicate that even the unequal wear of a single link destroys the nicety of its proportions.

157. *Eighth Advantage.*—The oscillating engine has much less friction. The trunnions alone supply the place of the whole of the numerous gudgeons in the common mechanism for transferring the motion from the piston to the crank, and they only sustain half the pressure exerted on the centres of the ordinary beam.

The plan I have adopted for reducing the friction of the trunnions, and putting them in fact in the position of ordinary bearings, will hereafter be explained.[6]

158. *Ninth Advantage.*—On account of the small number of rubbing parts in the oscillating engine, the consumption of grease is diminished. In my ordinary engines only eight bearings are oiled, and many of these have very small rubbing surfaces. If the lubrication be performed judiciously and with a view to economy, an engine of 10-horse power ought not to consume more than a large table-spoonful of oil per day.

159. *Tenth Advantage.*—The oscillating engine, when properly constructed, requires, on account of its great simplicity, less repair than the ordinary engine. This will be evident from an examination of the construction of my engines, as hereafter described. It is an old proverb, that where there is little friction, there will be little wear.

160. *Eleventh Advantage.*—The principal parts of the oscillating engine are in such a position, that if they become defective, the defects are sooner discovered and more easily rectified than with the common beam engine. I refer more especially to the position of the axis of vibration of the cylinder with respect to the crank-shaft. In order to facilitate the constant maintenance of these in a position perfectly parallel to each other, I have so arranged the bearings that they are capable of easy adjustment. Those who have had to do with the common

[6] See Art. 214.

beam engine know how difficult it is to keep all the moving parts, between the cylinder and crank, in a position of parallelism and perpendicularity with each other, and how many points are to be rectified when derangement occurs. In the oscillating engine, on the contrary, the adjustment can be effected by the aid of the simplest tests, known to every carpenter.

161. *Twelfth Advantage.*—The piston-rod of the oscillating engine requires no guiding. The stuffing-box suffices, when it is properly constructed with a view to this end. I have already stated that guides may be adapted to very large cylinders, and I will give in the after part of this work a plan for a simple arrangement of the kind; but in ordinary cases I do not deem them necessary.

162. *Thirteenth Advantage.*—Finally, in the oscillating engine the force of the steam is transmitted to the piston much more directly and advantageously than with the intervention of intermediate machinery; the whole action is more firm and steady; and the appearance at once strikes the eye with an impression of simplicity, solidity, and durability. The machine thus takes a higher and nobler character, and becomes more worthy of the exalted place it occupies in the economy of the world.

163. I hold that oscillating cylinders are less suitable for low-pressure steam engines than for high-pressure. The many pumps of the former take their motion in the simplest, firmest, and most secure manner from

the beam, and every attempt to get rid of this organ in such engines has been in a greater or less degree unsuccessful, rendering the engine not more simple, as was intended, but more complicated and inconvenient. I do not however undertake to assert that oscillating cylinders are under all circumstances inapplicable to low-pressure engines. It is possible to adapt them in such form as to avoid overloading them with complicated machinery, and they would then be very suitable and highly to be recommended for steam vessels.[7] I would not, however, devote time and trouble to such an adaptation, believing, as I do so firmly, in the superiority of the high-pressure system.

I have thus endeavoured to estimate the merits of the oscillating engine, and to show with what success it solves one of the most difficult problems we have in the construction of the steam engine, namely, to convert rectilinear into circular motion. I now proceed to consider the construction of the various parts of the engine, having peculiar reference to the high-pressure plan.

THE STEAM CYLINDER.

164. The cylinder is usually constructed of cast iron; sometimes of bell-metal or bronze. The latter is of course expensive, but is much preferable to cast iron, especially in cases where the engine has to make long stoppages. Bronze is not subject to rust, and does not suffer from moisture like iron. This is particularly important in reference to the packing of the piston when hemp is used; if rust forms on the sides of the cylinder,

[7] Witness the very general introduction of the oscillating plan for condensing engines on board steamers since this was written.—Tr.

the hemp packing soon becomes much injured thereby, and, in addition to this disadvantage, the particles of rust collect in the packing, and cause much damage to the cylinder by attrition. The only defect of brass cylinders is, that they wear away more at high temperatures than iron of hard quality, although, from the glossy nature of the surface of the metal, they give less friction and require less lubrication.

165. Whenever possible, no side channel should open into that end of the cylinder in which the piston is introduced after it has been taken out for packing. The sharp edges of the opening graze and scratch the packing, and thus often spoil it before it has worked at all. It is very advisable to bore out this end of the cylinder a little conical, to facilitate the introduction of the piston, and the channel may then open into the enlarged part, where its edges will not touch the packing as it enters.

166. The cylinder covers must be strong, and have projections entering into the cylinder, well fitted to their places. These projections also serve to strengthen the covers, as well as to fill up the vacant space in the cylinder where the steam-ports enter, and so to prevent waste of steam. For this purpose they should pass quite over the opening of the ports, and have a channel cut in them, to allow the passage of the steam. If the projections are turned slightly conical, the cylinder bored to correspond, and then both ground together, an excellent steam-tight joint may be made.

167. The stuffing-box for the piston-rod of an oscillating

cylinder must have a considerable length or height, not so much for the sake of the packing, as in order to obtain a good length of metal above and below it, to serve as a guide for the piston-rod. When the piston stands at the end of its stroke nearest to the stuffing-box, the distance from the outer end of the stuffing-box to that side of the piston most distant from it, should not be less than $1\frac{1}{2}$ times the diameter of the cylinder, (in the drawing it is more,) in order that the guidance may be secure in this, the most unfavourable position, and that the piston may acquire no tendency to edge (*ecken*) in the cylinder, or to be strained unduly towards either side.[8]

The stuffing-box should always be provided with loose bushes, so arranged as to allow of being turned partially round, and fixed by set screws, when they become worn oval by the side pressure of the rod: they then present fresh surfaces to the friction. They should also be easily replaced with new ones when this becomes necessary.

The hemp packing of the stuffing-box should never be too small: long and thick packings close softer and tighter round the rod than short and thin. I shall hereafter describe methods of lubricating the stuffing-box when it is placed on the lower cover of the cylinder.

168. The steam-jacket round the cylinder has formed the subject of much discussion. I believe that Woolf over-rated its advantages, but they are not to be altogether denied. I do not use a steam casing for the reason I

[8] It is a very good plan, where practicable, to allow the piston-rod to pass through both ends of the cylinder. This cannot, however, be done with the form of engine recommended by the Author, owing to the position of the slide-valve and its box.—Tr.

have elsewhere assigned, namely, that it dries up the moisture in the hemp packing, which is essential to its good condition. It is natural that there must be advantage in supplying free caloric to the expanding steam in the cylinder where it is deficient; but whether it is advantageous to abstract such caloric from the steam about to enter the cylinder, is quite another question.[9] Some engineers conduct a flue from the furnace round the cylinder, but this must endanger the packing of the piston.

I believe that the steam casing may be dispensed with if the outside of the cylinder be either polished, or surrounded with a covering of some bad conductor of heat, such as wood, felt, or thick cloth, over which, for the sake of appearance, a thin casing of iron or brass plate may be fixed. Or if this casing can be made air-tight, the sheet of air left between it and the cylinder will form the best non-conductor, and no other substance will be required. The simpler the arrangement is made, the better.

THE PISTON.

169. In a Paper published by me some time since, I have given reasons why I consider that pistons with metallic packings are unfit for steam engines working under high pressure; and have stated my conviction that the failure of Perkins's attempts to introduce steam of great elasticity arose from his making use of pistons of this description. My reasons for this opinion are grounded

[9] The Cornish engines are not so arranged. The jacket is supplied by a separate communication from the boilers: see 'Appendix G. to Tredgold,' Art. 97; also note on page 60 of the present work.—Tr.

upon known facts and long experience, although many practical men consider metallic pistons absolutely necessary for the high-pressure engine. I have become convinced of the contrary from the examination of many applications of the kind, where I have always found great friction and more or less loss of power result from their use; and I believe that to this cause the small useful effect of many modern high-pressure engines is to be ascribed. The pistons have often been very improperly made, both as regards the arrangement of their parts and the material of which they have been constructed. I will point out generally some of the more important difficulties which stand in the way of the favourable use of metallic pistons.

170. *First.* There are few manufactories which possess boring apparatus so perfect as to bore cylinders, particularly very large ones, with the great exactness absolutely necessary when metallic pistons are used. All those who know by experience the difficulty there is in fitting even small metallic surfaces together, with such exactness as to resist the subtle penetrating influence of high-pressure steam,—and, what is a greater difficulty, to retain their steam-tight condition when in constant motion upon each other,—such persons will easily imagine what an almost insuperable difficulty it must be to make the parts of a metallic piston fit and remain in perfect contact with so extensive a surface as that of a steam cylinder. It is evident that an extraordinary degree of exactness must be attained in the boring, or that a tedious operation of grinding must be gone through,—a process which often damages the piston, and makes it unsound, by the penetration of the grinding material into

its joints, and which after all only removes the lesser defects of the boring, while the more important ones remain. How often a good and sound-cast cylinder may be spoiled by imperfections in the boring apparatus, is unfortunately too well known to all who have had to do with machine making. It is almost superfluous to add that these difficulties increase with the diameter of the cylinder.

171. *Second.* The manufacture of a good metallic piston is fraught with as much difficulty as that of the cylinder. This increases, the more complicated the piston is in its design, and the more parts it contains which are required to fit steam-tight upon each other. Such work can only be expected to be done at first-class establishments, provided with the most perfect tools and apparatus for the purpose. A metallic piston must not even be of mediocre, much less of inferior, workmanship; it requires peculiarly skilful workmen for its manufacture, and these cannot always be met with in this world of imperfection.[10]

172. *Third.* A metallic piston, ground and fitted into the cylinder while in a cold state, alters its condition altogether under the heat and pressure of highly elastic steam. The heat expands the cylinder and piston unequally, if, as is generally the case, they are of different metals. The segments remain no longer concentric with the cylinder, and the proportions of the parts of the

[10] The Author is perhaps not cognizant of the almost unprecedented improvement in engineering tools which has taken place in England within the last few years. These difficulties, therefore, are by no means so formidable as they were.—Tr.

piston to each other become changed, whereby leakage occurs. In high-pressure engines, where the heat is greater, and the steam more penetrating, the evil becomes of course greater in proportion.

173. *Fourth.* Metallic pistons do not, as is generally supposed, grind themselves more perfectly steam-tight in working, but usually become more imperfect; their rubbing surfaces are soon more or less injured, particularly when the lubrication may chance to fail, or when an unsuitable metal is chosen. And when once damage begins, even in a small degree, the destruction of both piston and cylinder is quick and inevitable. The accumulation of rust in the cylinder after the engine has been standing, is a fruitful source of damage; as is also bad water.

174. *Fifth.* The separate parts of metallic pistons often stick so fast upon each other, by the expansion under heat, as to lose all mobility, and so to become quite useless. I have often seen instances of this kind with pistons which acted perfectly well when cold. The segments, be they of what metal they may, cohere firmly together, no matter how well they may be lubricated. I have already alluded to the greatly increased friction of metals when heated. Similar metals are worse in this respect than dissimilar; but dissimilar metals cannot be used in the manufacture of a piston, on account of the unequal expansion.

175. *Sixth.* Metallic pistons are subject to much greater friction than is generally supposed; according to

my experience, greater than those properly packed with hemp. Here again I must refer to the remarks made in Art. 148. Persons have been too apt to fall into the great error of estimating the friction by what it is when cold. I only became myself first aware of the mistake by finding that a piston of 6 inches diameter, which moved with a force of 6 ℔s. when cold, required much more power to put it in motion when heated. A metallic piston is under the great disadvantage, compared with a hemp packing, that the friction of the former always increases considerably with heat, while the latter works more easily, although still retaining its steam-tight condition. More than a hundred observations have proved this to me.

176. *Seventh.* The springs used for pressing the segments or rings against the cylinder, be they constructed of what form they may, lose their elasticity by great increase of temperature. This objection is also applicable to those pistons in which the rings are themselves elastic.

177. *Eighth.* The segments or rings must project somewhat beyond the top and bottom plates of the piston itself, in order that the latter may not rub against the cylinder. This annular projection, even though small, receives an injurious pressure from highly elastic steam.

178. *Ninth.* The segments or rings, as we have already said, scarcely ever fit so tight to the cylinder that high-pressure steam cannot intrude here and there between them. The consequence of this is a tendency to overcome the power of the springs, and force the segments still more

from the side of the cylinder, making the leak still larger. It may be said that the remedy is to admit the steam into the body of the piston, and make it act also in conjunction with the springs: this, however, has the evil of pressing the parts which do touch the cylinder, so forcibly against it, as to increase the friction to an enormous extent.

179. *Tenth.* In no metallic piston is perfect provision made that the several parts shall preserve their favourable proportions to each other as they wear away, so that the steam-tight condition may be preserved after considerable use, as it ought to be. In some, the arrangement of the segments, rings, or wedges, is such as to hinder their proper motion upon each other; and thus to prevent their favourable action as they expand.

180. *Eleventh.* Many metallic pistons consist of too many separate parts, segments, and rings, the fitting of which upon each other, so as to be steam-tight and to retain their free motion, involves endless difficulty. They are seldom perfect at first, and can never remain so long.

181. *Twelfth.* Many pistons wear the cylinder unequally. This is an old complaint brought against Barton's piston, the wedges of which are said to press forward with more force than the segments, and so tend to furrow or groove the cylinder.

182. *Thirteenth.* Metallic pistons are sometimes constructed of unsuitable metal; as for example, of tempered steel. This is very prejudicial, especially with high-pressure engines. I have myself noticed that steel pis-

tons not only cause great friction, but also quickly destroy the cylinder.

183. The difficulties above stated increase as steam of a higher pressure is used. All who have had so much and so long to do with great elasticities as I have, will confirm my opinion: those who have only been accustomed to pressures of two or three atmospheres may not agree with me; but I have already amply enlarged upon the insufficiency of such an elasticity for the efficient working of the high-pressure engine. I will now state the reasons why I prefer pistons with hemp packing to all others; these are as follow:

184. *First.* I have convinced myself that they work perfectly steam-tight under a pressure of eight atmospheres, provided that the piston and cylinder are in tolerably good condition, and that the packing is of good material and properly laid in.

I have frequently made experiments with my engines to ascertain if the packing were steam-tight, by fastening the engine in one position, and turning on steam of eight atmospheres' pressure. I seldom found any leakage worth notice, even though the piston moved with so little friction as to lead to the conjecture that the steam would blow through in streams. Hemp packing has been sometimes suspected of being unsound; but this I ascribe to the use of the steam-jacket, which deprives the hemp of moisture, and makes it shrivel up by the heat, and lose its steam-tight condition. A small degree of moisture is necessary to preserve to the hemp its cohesion and elasticity.

185. *Second.* Hemp packing has much less friction than many suppose. Experience has proved this to me. One of the most striking instances was with an engine of 2-horse power, which once worked so easily, that I was curious to examine the packing. I found it tight under a pressure of six atmospheres, and yet the 6-inch piston was moved with a force of scarcely 10 ℔s.

Since the introduction of metallic pistons, many attempts have been made to bring the hemp packing into discredit, and many charges have been brought against it, particularly on the grounds of leakage and friction, without proper investigation as to whether they were well founded or not. Bernouilli[11] states the friction of metal and hemp packings to stand respectively in the proportion of 3 to 4; my experience would lead me to invert the ratio, making metal the greater, that is, when the cylinder and the packing are in good condition. I have constantly the fact before my eyes, that the piston may be tight under a pressure of eight atmospheres without any great depth of packing, or formidable pressure against the cylinder, and consequently without any great friction.

I have before remarked on the fact, that a great advantage of hemp packing is, that its friction decreases with heat, while with metal the reverse is the case. I have often known the friction of the former only one-fourth or one-fifth as great as in a cold state. This diminution has often astonished me, and I have found it somewhat difficult to explain. The cylinder certainly expands, but so does the piston also, and the packing swells too, both from the action of the heat and the moisture. Whatever be the explanation, the fact is certain, and may be proved by any

[11] 'Handbuch der Dampfmaschinenlehre,' p. 240.

one who will try it for himself. Had this and the following advantage been more known and considered, we should have heard less about metallic pistons in modern days.

186. *Third.* Hemp packings, when well attended to and lubricated, are much more durable than is generally supposed. I have retained them half a year without their losing their soundness in the least, or the hemp being in the least destroyed. In bronze cylinders they would last still longer. It is therefore an unfounded calumny against hemp packing to say, as some do, that it requires constant renewal, at great trouble and expense; for even when the renewing is required, hemp is so cheap a material, that under good arrangements the cost is insignificant; and though the operation certainly requires care, it is neither troublesome nor laborious. Nor is the occasional screwing down of the packing a matter worth mentioning: but when once a *metallic* piston gets out of repair, the expense and inconvenience become serious indeed.

I give then, on the whole, decidedly the preference to hemp-packed pistons for high-pressure steam. This judgment on my part may be considered impartial, since I have not only had good opportunity of practically trying both kinds, and of gathering information respecting them, but have also myself invented two metallic pistons[12] which I think may not be classed among the worst of the kind.

[12] Described in Dingler's 'Polytech. Journ.' vol. xxxii. page 153.

[This opinion of the Author against metallic pistons is one which English engineers will be likely to differ from. The piston now so much used in England, consisting of a single elastic ring with a tongue-joint, is certainly free from many of the Author's objections, and in many cases works exceedingly well. It is not to be wondered at that he rejected all the old complicated combinations of segments, springs, &c.; but whether he has tried this simplest of all forms does not appear.—Tr.]

187. The common hemp rope-yarns (*Hanfflechten*), consisting simply of hemp twisted loosely together, make, when the cylinder is clean and polished, by far the best packing. They allow of being laid firmly round the body of the piston, are spongy and elastic, adapt themselves steam-tight to the sides of the cylinder, absorb the grease with great avidity, and retain it a long time. It is doubtful, however, whether it is prudent to use these when the sides of the cylinder may have suffered from rust and become rough: the fibres are in too loose a condition, not bound firmly enough together, are too little twisted; they soon get loosened by the friction, and are decomposed and blown out in small particles with the steam from the cylinder. I was particularly impressed with this fact on one occasion, when, from some unknown cause, (possibly the presence of free sulphuric acid in the tallow,) the cylinder of my Güstrow engine became somewhat roughened. The hemp packing of the piston, which had already worked satisfactorily, and remained perfectly tight for a quarter of a year, suddenly became leaky, the engine blew through, and its power could scarcely be kept up with even a very strong fire. When I removed the piston for examination, I found its packing entirely decomposed on one side, and a considerable piece of it gone. Not suspecting then the state of the cylinder, I attributed the decay of the packing to too long wear, and replaced it with a new one, fully expecting this to remedy the evil. How astonished was I to find the same symptoms occur again after only two days. The experiment was repeated with the same result. The engine could not be stopped to re-polish the cylinder; I therefore packed the piston again, using this time loose

unspun hemp, which however was destroyed in half the time of the former. I then tried a gasket of hempen string about the thickness of pack-thread, and had the satisfaction to find this answer well, enduring much longer than I had expected. It was made by a rope-maker entirely in the common way, but twisted so that each of the three twists of the gasket contained four or five threads of the hempen string. I discovered afterwards, however, that this packing, when the cylinder was re-polished, caused more friction, retained less elasticity, and required more attention than the kind I have above described: I therefore am inclined to prefer for most cases the rope of loose unspun fibres, and strongly recommend that care should be taken to keep the cylinder in a good and smooth condition, that the packing may work well and last long. This is best attained by lubricating at the proper times, and with good pure grease, taking care to add a sufficient quantity to cover the sides of the cylinder when the engine stands: at this time also the throttle-valve should be carefully shut, that no steam may enter and condense in the cylinder; the moisture left behind will be soon evaporated by the heat. The piston should be left low in the cylinder, and the crank turned a little, that the eduction port to the upper part of the cylinder may be opened. The grease will then be left alone behind, and will preserve the iron from rust. Bronze cylinders require of course less care of this kind.

188. Much injury is done to hemp pistons by bad tallow, particularly such as contains much animal fibre or membrane. These substances stick fast and harden in

the hemp, and make the packing stiff and hard, whereby the qualities necessary to a tight and elastic condition are impaired. One cannot exercise too much caution with respect to the kind of tallow used. If it is found to leave a dark brown sediment upon the cylinder and in the stuffing-boxes, it is not fit for use. Most vegetable oils contain a slimy substance which penetrates into and hardens the packing, and therefore these also should be condemned for this kind of lubrication.

ON THE LENGTH OF STROKE.

189. In modern times, particularly in America, a very long stroke has been introduced, principally for steam vessels, where one would think it was least applicable on account of the want of height. Much difference of opinion has prevailed on the subject of the length of stroke; I will state the results of my own experience.

Although I well know that a reciprocating motion is always accompanied with loss, and that this loss is increased as the rapidity with which the motion is changed increases, I am yet inclined to think that this disadvantage has many modifying circumstances in practice, and is influenced in an important degree by the construction of the engine, and the size and weight of the parts put in reciprocating motion. It appears to me that the low-pressure engine, working with a massive beam and heavy connecting machinery, is particularly well suited to a long stroke and a slow velocity of the piston. Watt gave his engines a longer and slower stroke principally in order to gain time for condensation, but this motive falls entirely away with the high-pressure engine.

I prefer a short stroke for my engines, unless special

circumstances require it to be otherwise; taking care, however, to make suitable provisions in the construction of the engine, *i. e.* to put smaller masses in motion and to make the steam passages sufficiently large. I construct all the reciprocating parts strong and durable, and I give the whole machine great firmness and stability. With such precautions I have never known any perceptible disadvantage arise from the shortness of the stroke.

In many respects, however, an engine with a short stroke and quick motion has manifest advantages over one on a contrary construction. Such are—

First. It does not require so large and heavy a fly-wheel, and therefore suffers less loss from friction.

Second. It may have lighter driving shafts, another cause of diminished friction.

Third. A quicker motion allows a more extensive and successful use of the principle of expansion, the inequality in the action being less felt.

Fourth. Engines with a short stroke take much less room, are more compressed and compendious in their form, and have greater stability and solidity. My engines never require great height, a circumstance which gives them many advantages.

My experience has never confirmed the common opinion as to the disadvantages of a short stroke and quick motion. It is said that engines so built require more repair than those on the contrary plan, but I have not found this, when care has been taken to give the parts sufficient strength, and to place the engine on a good and steady foundation. My engines, at least, have never given me reason to complain on this ground, and I

trust to the correctness of the scriptural test, "By their works ye shall know them."

I am acquainted only with one disadvantage to the use of a short stroke and quick motion, namely, that the cylinder and piston-rod are subject to more attrition, being rubbed over oftener as the motion is more frequently changed in a given time. Whether, however, this objection is worthy of mention in opposition to so many valuable advantages on the other hand, particularly with the small high-pressure cylinder, is another question. If good hard metal is used, the engine will work for many years without this evil being felt.

190. Attempts have been lately made to adapt single-acting engines to produce circular motion: this is, in my opinion, a retrograde step. The discovery of the double-acting engine by Watt was one of the greatest triumphs of his age: it was received on all sides with admiration, and speaks its own merits as clearly as they have been proved by universal experience. The attempt to go back to the old imperfect fashion is to me unintelligible. Is it supposed that because the great Cornish pumping engines give a high duty, there is a magic in their single action? or is it thought that the steam is so self-willed as to refuse to follow the same laws below as above the piston?

ON THE VALVES.

191. The valves[13] used for steam engines may be

[13] *Steurung*, literally *steering*, is a general term for the whole apparatus by which the steam is caused to pass alternately into and out of the cylinder. We have no corresponding word in English.—Tr.

divided into two great classes. One comprises *conical, seat,* or *stalk-valves;* the other, *slides, pistons,* and *cocks.*

In the first class the steam channels are opened and closed by conical plates falling into fixed seats to which they are ground. The valves are furnished with stalks, serving partly to guide them, and partly to give them motion from without the box in which they work.

The second class includes all valves in which the channel or port is closed by a metal plate, sliding steam-tight upon it; at one time closing it by a blank surface of metal, at another presenting to it a corresponding hole, through which the communication is left uninterrupted.

192. It is plain that the valves of the first class shut the communication by simple steam-tight contact of their surfaces, without rubbing; while the latter, having metal surfaces sliding upon each other, are subject to considerable friction, which increases to an important degree in high temperatures. Hence the first class of valves would have a decided preference over the second, particularly for high-pressure engines, were they not accompanied by many inconveniences which outweigh their good qualities in a greater or less degree. I have only discovered the existence and weight of these inconveniences by keeping up a long and unpleasant warfare with them, in which I have been compelled to confess myself beaten. During my earliest practice with high-pressure engines, I not only preferred stalk-valves, but considered them indispensable for this kind of engine. At that time, however, I wanted experience, and I worked, moreover, with a much higher elasticity than I have since found it expedient to use.

Further practice has changed my views on the subject, by showing me the great defects of these valves. I will relate the results of my experience as briefly as possible.

193. *First.* Stalk-valves require very complicated machinery, even when made with every regard to simplicity. All the rods must pass steam-tight through stuffing-boxes, of which there must be at least four, and these require much care, attention, and lubrication.

This, however, is not all the evil. Each valve must have an especial motive apparatus for itself, involving the use of many pieces of mechanism, and many joints, which require much trouble and exactness in the manufacture, cost much money, and are often liable to damage, owing to the frequent concussions and jerkings they are subject to in their motion.

The greatest difficulty, however, is, that the gearing must not only open the valve, but must also shut it again, in such a manner as to deposit it gently in its seat, that it may not receive an injurious shock from the action of the steam suddenly forcing it down. Moreover, the end of the motion must exactly correspond with the position of the valve in its seat, to avoid injurious strains. These are difficult problems to solve, especially with oscillating cylinders, where the whole apparatus is in constant motion, and where the necessary closing of the steam-valve for expansion is scarcely possible to be arranged by the ordinary gearing.

194. *Second.* The steam, when of high elasticity, exercises a great pressure upon the stalk-valves, and

renders them very difficult to open, giving great and injurious strains to the whole apparatus. The Cornish double-beat valve[14] removes indeed a great part of the pressure, but is complicated and difficult to make, and cannot be used for small engines. Balance weights and springs do no good, as the strain is not constant, but only exerted at a particular moment.

195. *Third.* Stalk-valves soon lose their tight contact, and become leaky. Strange bodies easily get upon the faces, and soon become so tightly hammered in by the pressure, that the current of steam has no longer power to force them away. Such are especially sand, small particles of wood or metal, rust, fibres of hemp from the packing, or bits of lead from the joints, dirt of many kinds which may come over from the boiler, and so on. The name of such substances is legion, and it is exceedingly difficult to keep the valves free from them, even when the greatest care and cleanliness are observed. The worst of the kind are those which are hard and sharp, such as sand or particles of metal; these often stick fast in the faces, and damage them so that they can only be repaired by re-grinding. In many of my first engines constructed with seat-valves, the interruptions from this cause became excessively troublesome: notwithstanding the engines were under my own care, and the greatest attention was bestowed upon them, their action could never long be trusted to, and the valve apparatus was always found to be the root of the evil. The seat-valves were finally removed and replaced with slides: in the largest engine, these have worked now

[14] *Vide* 'Appendix G. to Tredgold,' Arts. 112 to 115.—Tr.

several years, and have never once been in disorder, or interrupted the action of the engine. The slide-valve, when it is once ground tight, has a tendency to remain so, and to remove, instead of fixing, all extraneous matters.

Another cause of the leakage of stalk-valves is their not falling true into their seats, whereby they bear more against one side than the other. This may be occasioned by several causes; as imperfection in the packing of the stuffing-boxes; or unequal screwing down of their glands; or want of truth in the machinery. Many attempts have been made to get rid of these evils, and I myself have striven to do so; but the chances of derangement are so many, that it is an endless contest, and even the most determined and persevering efforts must at last give way.

I need scarcely add that the leakage assumes a much more alarming aspect with a subtle and penetrating fluid like steam of eight atmospheres' elasticity, than with ordinary pressures: the least faults become here of the highest importance.

196. In short, according to my experience, seat-valves are wholly unsuitable for high-pressure engines: they are never trustworthy or secure; they require double attention, exactness, trouble, and patience, and do not act perfectly after all. I therefore decidedly recommend slides; I have tried them during a period of eight or ten years, and have had no reason to be dissatisfied with them. Although working under great heat and pressure, they have caused no important friction, nor suffered any great wear.

197. In thus preferring the sliding principle, however, it must be understood that I am far from recommending the whole of the valves comprehended under the second general class I have named, *i. e. all valves which slide*, including cocks, pistons, &c. I only refer to the single variety with flat surfaces, known in England by the simple name *slide*,[15] and which I shall hereafter describe as adapted to my engine. Pistons are very defective, and cocks the worst kind of all: they wear unequally, are constantly either too loose or too tight in their sockets, and cause endless trouble.[16]

198. One great advantage of the slide-valve is, that it requires only the simplest gearing; one single backward and forward motion suffices, and this, in my engines, is supplied by the motion of the cylinder itself, merely requiring an arrangement of the most simple kind to connect the slide-rod with a fixed point in the framing of the machine.

199. It has generally been thought that a serious objection to the slide-valve lies in the great pressure upon it, under steam of a high elasticity, and the great friction caused thereby. I was originally of this opinion, and considered that this evil disqualified all sliding apparatus for the valves of high-pressure engines; and even when I later gave the preference to slide-valves, I spent much trouble in endeavouring to contrive methods of lessening

[15] Or three-ported valve; it is more generally used than any other.—Tr.

[16] Cocks are imperfect and troublesome machines in even the commonest situations where they act under heat. How much more so then for such a purpose as that alluded to in the text.—Tr.

the pressure, and consequent friction. Experience, however, which is the best teacher, has convinced me that the objection has much less weight than is generally imagined, and that in reality no such contrivances are necessary. The power consumed in working the valve is but small, and it must be recollected that in high-pressure engines, although the pressure is greater, the surface of the valve is much smaller in proportion to the power of the engine.[17]

STEAM AND EDUCTION PASSAGES.

200. Unpardonable mistakes are often committed in reference to the size of the openings by which the steam passes into and out of the cylinder, particularly with high-pressure engines. I believe the cause why so many engines of this kind act badly is a defective arrangement of the eduction passages. Watt laid down a rule which is universally applicable, but which seems not to have been sufficiently attended to in modern days. He gave the proportion between the diameter of the cylinder and that of the steam and eduction-pipes, as 5 to 1; and according to my experience this answers well for high as well as low-pressure engines. I have often found inconvenience and loss of power from the eduction passages being too small: sometimes the condensed water collecting in the

[17] The power consumed in working the valve may be estimated thus to a tolerable approximation. In the engine drawn in the Plates, the area of the valve is about $\frac{1}{3}$ the area of the cylinder; and supposing the co-efficient of friction between the surfaces $= \frac{1}{10}$, the force required to move the valve will be $= \frac{1}{30}$ that on the piston. The valve travels over about $\frac{1}{10}$ the space that the piston does, and therefore the *work* or power consumed in working the valve will be $= \frac{1}{300}$ that of the engine; *i. e.* if the engine be 10-horse power, the valve will require about $\frac{1}{30}$-horse power.—Tr.

passages would offer a very serious opposition to the exit of the steam, and cause so great an extra resistance to the engine as to reduce its velocity one-third, until the pipe was cleared. I have before had occasion to notice the extraordinary fact, that when the steam blows out freely at a considerable pressure, it tends to form a slight vacuum before the piston :[18] it is easily understood that to produce such an effect the exit must not be confined.

EXPANSION.

201. I always make use of the principle of expansion in my engines, cutting off the steam generally at one-third of the stroke by means of a separate slide worked by the principal valve. This arrangement simplifies exceedingly the machinery, requiring only one stuffing-box, and no separate apparatus for working the expansion slide.

[18] *Vide* note on page 56. On a late visit to the Author I took occasion to ask him some more particulars respecting the singular fact mentioned in this note, namely, the apparent production of a partial vacuum before the piston by the sudden blowing out of the steam. He not only repeated more fully the evidence derived from the grease-cock drawing air, but related another fact still more conclusive.

He had erected an engine in a small steamer, and the waste steam was discharged at a pressure of about three atmospheres through a long eduction-pipe of tin plate, leading from the engine to the funnel. This pipe, being weak, was observed to suffer a kind of collapse,—a sort of squeezing inwards, every stroke, at the moment the steam blew through: it remained so some time, until one day while Dr. Alban was standing near, the sides of the pipe were suddenly compressed flat together with great force and with a loud report, in a manner which could only have arisen from overpowering external pressure. The pipe was hot, there was no rain, nor any cause that could have condensed the vapour inside; and in this case, as in that of the grease-cock, the relator (who must be allowed to be no inexperienced observer in such matters) declares he could give no reasonable explanation of the reduction of the internal pressure, except that assigned on page 56. These appearances were only observed when the steam was discharged at considerable pressure, viz. about three or four atmospheres.—Tr.

Much difference of opinion has been expressed with reference to the degree of expansion most advantageous to be used: many theoretical calculations have been made to determine the point, but they all appear contradictory and unsatisfactory. Practical considerations form the best guide, and these are often left entirely out of view by mere mathematicians. Although theoretically the economical advantage increases with the degree of expansion used, it is evident that a practical limit must be assigned by the inequality of the steam's action on the piston.[19] It is, moreover, necessary to consider the pressure the steam should have on its leaving the cylinder. Experience gives the best rules on these points. Oliver Evans, who had much practice with pressures such as I use, cut off the steam in his engines at one-third the stroke: I have adopted the same proportion, as a golden mean, and have found it perfectly satisfactory. The action is sufficiently regular, not requiring any extra weight in the fly-wheel, and yet a considerable economical benefit is gained.[20]

[19] As well as by the reduction of power, or greater size of cylinder required to do the same work.—Tr.

[20] The Author gives in the original an elaborate answer, occupying 20 pages, to a Paper by Mr. G. Holworthy Palmer (published in the 'Trans. Inst. C. E.,' vol. ii. page 33), the object of which is to deny the advantages of expansion. I have not thought it necessary to insert this, as I cannot believe these advantages are any longer questioned. After all that has been said and written on the subject of expansion, I know no better, simpler, or more convincing proof of its advantages than that given by Watt in his original patent of 1782.

The Author appears to have taken great pains to make himself master of his subject; his remarks contain much sound sense and forcible reasoning.

Some persons have an idea that the benefits of expansion may be realized by merely *throttling* or *wire-drawing* the steam as it passes from the boiler to the cylinder. This is a strange delusion. The object of expansion is to work the steam *twice over:* without this there can be no gain.—Tr.

Some manufacturers have made the governor of the engine to act upon the expansion apparatus, instead of on the throttle-valve. This is, according to my opinion, an arrangement the advantages of which by no means compensate for its trouble and complexity.

THE CONDENSER.

202. A condenser is only advantageous for a high-pressure engine under certain circumstances, and then it must be of the simplest possible construction, with no air-pump. This pump is fortunately not necessary when high-pressure steam is used, as the steam blowing out from the cylinder may be made to act in its stead. The gain of the vacuum, where it can be simply obtained, is certainly worthy of consideration.

203. The circumstances under which a condenser may be favourably adapted to a high-pressure engine are,

First. When there is an abundance of cold water at hand, without requiring much cost or trouble to obtain it.

Second. When the engine is very large, and the gain by condensation consequently more important. Or,

Third. When the steam blowing out from the engine cannot be used for any useful object. This does not often happen, for there are few engines where there are not at least rooms to be heated, or water to be warmed, or something of that kind which will give a greater advantage from the waste steam than the application of a condenser.

The condenser for a high-pressure engine may be either

with or without injection: in both kinds the water and air may be driven out by a blast of steam every stroke. The water should not be used for feeding the boiler, on account of the grease it contains. (See Art. 104.) My condensers are in the highest degree simple, consisting only of a single pipe and a valve, with a small cock where injection is used. I shall describe them hereafter.

DESCRIPTION OF THE AUTHOR'S ENGINES.

204. I now proceed to describe my engines, and the various apparatus belonging to them, more in detail.

The kind of engine I recommend as a normal form, for all cases in which peculiar circumstances do not render a different arrangement preferable, is shown in Plates XII. XIII. XIV. XV. Figs. 54 and 55 are a front and side elevation respectively; and figs. 56 and 57, sections, both taken in the axis of the cylinder. The same letters refer to the same parts in all these figures.

The figures represent an engine of 10 horse-power. The dimensions may be found from the scales.

205. *The Framing.*—This is entirely constructed of iron; wood being too changeable for the purpose. The form is Doric, and the general dimensions and proportions may be obtained from the figures. I will confine myself to describing the manner in which it is put together, and such other particulars as more especially interest the manufacturer.

The whole frame consists of six principal parts, fastened together with four strong bolts, and forming a solid whole which experience has shown to be perfectly firm and free from vibration under all circumstances, although its

base is not very extended. These parts are, the top plate A, the four columns B, and the bottom plate C, all of cast iron.

The top plate is 7 inches wide, the bottom one 10 inches, and both are $1\frac{1}{4}$ inch thick, strengthened with ribs *a a*. In the four corners of the top plate, where the columns are fixed, the metal is thickened $\frac{1}{2}$ an inch between the ribs, as seen at *a a* in figs. 60, 61, and 88; and the inner angles of both the top and bottom plates are filled up, in the manner shown at *b*, figs. 61 and 62. The attachment of the columns to the plates is seen clearly in these figures.

The columns are fluted, and are cast hollow, leaving metal of sufficient strength for firmness and solidity. The lower end may be thickened a little as at *f*, fig. 59. The capitals are cast separate; the manner in which they are fixed to the columns is shown at *e e*, fig. 60; at *d*, fig. 61, the angle is filled up, that the corner (*c*) of the top plate may rest upon it.

The bolts for screwing down the columns are of considerable strength, and furnished with strong nuts. The head of each must be securely welded on, and the bolt formed square under the head, to pass through a square hole in the bottom plate, and prevent the bolt from turning when screwed up. Wrought iron washers are placed under the nuts, and the upper surface of these should be slightly oiled, to diminish the friction when the nuts are screwed up tight.

The bottom plate stands on a plinth or sill-frame of dry sound oak, and this must be bedded on a foundation of solid deep masonry: if the ground is bad, piling should be resorted to, as the foundation cannot be too

secure. The bottom plate should be screwed down to the sill and to the foundation by eight strong holding-down bolts, passing through the whole.

The entablature E is a box of cast iron bolted upon the upper plate; it fits over the rib of the plate, coming flush with its edge, and forming a handsome completion of the Doric design. Its interior serves to contain much of the machinery, as will hereafter be described. The Doric triglyphs, &c., are of cast iron, riveted on: the cornice is of good dry oak, slipped over from above; it should have a plate of wrought iron on its top, to prevent its edge being injured when a ladder is reared against it.

206. The plummer-blocks for the trunnions are fixed upon the top plate A. They are of the usual construction, furnished with *brasses* of good hard metal. They are shown in figs. 63 and 64. The manner in which they are adjusted and fixed down to the plate is important. *g g*, fig. 56, are two snugs cast upon the plate, between which and the ends of the plummer-block wedges are driven, to adjust and secure the bearing so that its centre may correspond with the vertical centre line of the engine. The adjustments in height and level are performed by four set screws *h h*, figs. 63 and 64, by which the trunnion axis may be laid horizontal: after these screws are adjusted, the plummer-blocks are fixed firmly down by the two holding-down bolts *i i*. These arrangements for adjustment are absolutely necessary, that the swing axis may always be kept parallel with that of the crank-shaft,—a very important condition for the oscillating engine, if it is to work well.

The bottom plate receives, between the columns on one of its sides, the plummer-block for the crank-shaft. The plate is made somewhat wider on this side than on the three others. The plummer-block is shown at K, fig. 57. It is of the usual construction; it lies upon two ribs cast on the bottom plate, and is secured from lateral motion by wedging its ends against two fixed snugs, as described in the last article.

The brasses for this and other plummer-blocks I usually make round instead of six or eight-sided, as customary; they are so much more easily fitted in the lathe. To prevent them from turning in the plummer-blocks, I fix them with pins of the same metal; the upper brass is fixed by a brass screw which also serves for lubrication; it is clearly shown in the figure. The small oil-cup should have a cover, to prevent dirt getting in.

207. *The Cylinder.*—This is of the usual construction, having at each end a flanch to which the covers are bolted. On the upper flanch, however, are two strong ears, serving to fix it to the trunnion frame; they are of the same thickness as the flanch itself; in the drawing they are 2 inches thick and 8 inches wide. The trunnion frame has a groove to receive these ears, and is screwed to them with two or three bolts on each side. In fig. 56, *v v* are the ears, and *u u* are the sides of the frame in section. The latter is seen also in figs. 70 and 71. On one side of the cylinder is cast a channel for the passage of the steam from the valves to the lower end of the cylinder; or, which is better, the two sides only of this channel may be formed in the casting, and a cover screwed on: there is then a less chance of the casting

being a bad one. The channel opens with an oblong rectangular port in the cylinder, and its section in the 10-horse engine is 3 inches by $\frac{3}{4}$ inch. Its sides should be smoothed and polished, that the steam may have as little hindrance as possible in its motion. In fig. 56, this channel is shown at w; y is its upper and x its lower end.

The cylinder must be well and equally bored, and polished smooth. I make it a little conical at each end, and turn the covers to correspond. See Art. 166 for the object and advantage of this provision.

208. I surround the cylinder with a thin casing of cast iron or sheet brass, which stands so far from the cylinder as just to cover the steam channel on its side. The casing should be fluted, to correspond in appearance with the columns of the framing. Between the casing and the cylinder I place either wool or some other bad conductor of heat; or if the casing is air-tight, the stratum of air is the best protection.

209. The upper cover receives the valve apparatus, and will be more particularly described with this.

The lower cover contains the stuffing-box for the piston-rod, and is bolted to the cylinder flanch with good 1-inch bolts. The joint is made tight with a lead ring, which is prevented from squeezing out sideways by means of a groove in the flanch and corresponding projection on the cover, on the same principle as explained in Art. 93. These are shown in fig. 65 at *a*.

The cover has a projection entering into the cylinder to a distance about $\frac{1}{4}$ inch beyond the inner end of the

steam-port, a groove being cut to allow the passage of the steam: see fig. 56 at *z*. The object of this projection is to diminish the waste space in the cylinder. See Art. 166.

I have already spoken of the necessary requisites for a good stuffing-box. For small engines on the oscillating plan, it must perform the office of a guide to the piston-rod as well as a packing. It must therefore be much longer than usual. (See Art. 167.) An examination of the stuffing-box shown in section in figs. 56 and 57 will show the construction and dimensions I have adopted: 1 is the body, 2 the packing, 3 the gland or cover.

An arrangement for lubricating the piston-rod is shown in fig. 65, which will be understood without much description: *b* is a loose brass ring surrounding the piston-rod, having a channel in it communicating by the hole *c* and small pipe *d* with the grease-cup *e*.[21]

Or another and very simple method of lubrication may be adopted, viz. by laying tallow upon a lap of cloth, and smearing frequently the piston-rod therewith: I have found this quite effectual when carefully done. The rod always receives a certain degree of lubrication from the grease in the inside of the cylinder.

The gland or cover of the stuffing-box (*Stopfpropfen*) is furnished with a bush of hard gun-metal, fitted in such manner that it may easily be turned partially round from

[21] The Author informs me he has never found this apparatus necessary. The method shown in fig. 58 is a more simple one, and perfectly effective. No description is necessary, further than to explain that in addition to the principal grease apparatus, *a* is a recess sunk round the rod, which collects the grease and greasy water dropping from the cylinder and piston, to assist in the lubrication.—Tr.

time to time as it wears, or may be removed when a new one is required: it is fastened in its position by four set screws, *h h*, fig. 65. A similar provision should also be made, so far as is practicable, with the bush at the other end of the stuffing-box: *i i* is a shoulder, which, if ground into its place, much assists in keeping the whole in a steam-tight condition; as the steam will often escape behind the packing when it cannot penetrate between the packing and the rod.

The cover of the stuffing-box is screwed up by eye-bolts, which may have double nuts for security, if desirable. When, however, the cover is well fitted and ground into the box, so as to be free from shaking, there is not much danger of the nuts working loose.

210. *The Piston.*—I have already stated why I prefer pistons with hemp packing for high-pressure steam. My piston is of the usual construction, but reversed in position, the rod passing downwards.

There is a peculiarity in the method of screwing forward the piston-ring upon the packing. I have often remarked that the ring and its screws become gradually loose as the packing gives way, and that when this occurs, injurious concussions take place, which may often result in serious damage. I therefore arrange the screws as shown in figures 65, 66, and 67, where *p p p p* are bolts to screw the ring up upon the packing (seen in section in fig. 65), and *q q q q* are set screws (seen in fig. 67) to hold it tight in its position. Of course one set of these screws must be loosened when the other is tightened. The heads of the set screws must be let into the ring, and their length be

so arranged that they take up no more room in the cylinder than is absolutely necessary.[22] The set screws *q q* are also often useful to loosen the ring when it has to be removed for packing.

The body of the piston, as used for small engines, is shown in figs. 65 and 67, which also explain the manner in which the piston-rod is secured to it. *b* is a conical shoulder on the rod, ground steam-tight into its place, and *c* is a strong nut by which the rod is secured. In order that the rod may not turn and get loose, it is provided with a plate *d*, welded upon the rod, which holds upon the piston by a pin *e*. The nut is prevented from turning by a small screw, or a wedge, or in any other of the methods well known to mechanics. The connection of the piston to the rod ought to be very firm and strong; they have seldom to be disunited.

A brass plate, slightly convex, may be fitted over the whole top surface of the piston, to prevent the grease from penetrating into the interior, and to guide it against the sides of the cylinder.

211. In Art. 187 I have described the manner of using the hemp in packing. The fibres should be beaten, in order to render them soft, and to clean them from the resinous and glutinous matters which hang upon them and cause them to adhere to each other; they are then spun into loosely turned cords, of barely $\frac{1}{4}$ of an inch diameter, three to five of which are firmly

[22] The necessity of *locking* the screws of the piston-ring is well known in England, and provided for by several familiar expedients, such as the locking-ring, &c.—Tr.

twisted into a rope or gasket, according to the thickness of packing required. The piston being taken out of the cylinder, and the ring being drawn back to its full extent, one end of the gasket is fastened into a hole on the projecting edge, by driving a wooden plug in with it. It is then wound carefully round the body of the piston, beating the coils as close as possible together with a wooden mallet: when this is finished, the last windings are beaten fast upon each other, and the end of the rope is turned in and also hammered under the last coil: the whole is then subjected to gentle blows with the mallet, by which all bucklings and irregularities of surface must be beaten down.

The piston should be then tried to the cylinder. If the packing is too large, it should be beaten down to smaller dimensions with the mallet; if too small, the ring should be screwed a little forward, so as to press out the hemp, after which, the ring being drawn back to its former position, more hemp may be laid in, properly securing the ends: a little experience will soon give skill in arranging properly the size of the packing. When the piston is made to enter, I grease the packing with melted tallow, and drive the piston in with a large hammer, (taking care, however, that the blows do not fall upon the piston itself, but upon a block of wood placed between,) until I can connect the rod with the crank, and so force it in further by turning the fly-wheel, after the cover is in its place. It is no disadvantage if considerable force is required at first to make it enter; it will soon move more freely: if it goes in too easily, the ring must be screwed up tighter.

It is requisite to tighten the ring of a newly packed

piston at least once a day for the first three or four days. After this, it should be looked to once a week, or once a fortnight, and soon this becomes no longer necessary. The observation of the manner in which the steam blows out from the cylinder suffices then to indicate the condition of the packing. For this purpose a small opening should be made in the eduction-pipe, and stopped when out of use with a wooden plug.

Immediately after packing, the piston should be plentifully supplied with grease, that the hemp may become well saturated. At a later period it should be lubricated once in two or three hours. It is best to give a little at a time, since if too much is poured in, it is blown out again to waste. This regulation is also applicable to the packing of the stuffing-boxes, and to packings in general. When the engine is stopped after a day's work, a good supply of grease should be given to the cylinder, to preserve it from rusting: see Art. 187.

212. The lubrication of the piston is effected in my engines in a peculiar way, altogether different from the method usually adopted with high-pressure engines. The necessary apparatus is shown at *a* in fig. 74. *b* is a small valve, with a three-cornered stalk, opening into the cylinder, and kept closed by a small spiral spring. *c* is a grease-cup, hollowed out in the metal.

The cup is filled with tallow, which soon becomes properly melted; the steam is then shut off from the engine for an instant before the commencement of the down stroke, and the motion of the piston causes the grease to be sucked in so quickly, that if the operation

be skilfully performed, no sensible interruption of the action of the engine will be caused. A few trials will give the requisite skill in the management of the apparatus.

This plan has the advantage over grease-pumps or cocks, that the grease is more forcibly injected, and better distributed, by the conical form of the valve, against the sides of the cylinder. It is better not to put more grease into the cup than is actually required, that air may enter with it, and assist in its dispersion.

If a grease-pump is preferred, it can be easily applied and worked by the motion of the cylinder itself; but I would in no case advise the use of cocks. They soon lose their steam-tight condition, and allow the steam to blow the grease out of the cups, causing much trouble. I have often tried them, but invariably repented, and have now entirely rejected them.

213. In my latest engines I have made use of a different arrangement of piston to that described above. It is shown in figs. 68 and 69, the former being an external view, and the latter a section. *a* is the body of the piston, *b* the rod, *c* a ring or cover, fastened firmly upon the piston by the screws *d d*. A loose ring *e* is fitted round the piston so as to slide easily upon it. The packing is placed at *g*, and the ring *e* is pressed against it by the screws *f*, which have clamping nuts to keep them in their given position. There is a groove cut round the lower cylinder cover to receive the heads of these screws, whereby the clearance or waste space in the cylinder is much diminished. (See figs. 56, 57.)

It will be remarked that in this piston the compressing ring is flat on the side which presses against the packing; the wedge-like form, that tends to thrust the hemp outwards against the cylinder, is wanting. Such a form is not necessary, and the flat one has the advantage of not endangering the texture of the hemp, which is often injured by the forcible action of the wedge-like ring in the common arrangement.

In packing this piston I cut the ropes or gaskets into separate lengths, equal to the circumference of the piston, and sew the two ends of each together, forming a number of rings, which exactly encircle the body of the piston, and are laid around it, breaking the joints, in sufficient number to compose the packing. This method of packing is much more convenient than the former, and may be done without removing the piston from the cylinder.

When the engine is large, the piston should be cast hollow to save weight; it is shown so in fig. 69, where *a a* are vacuities. These may be filled up with wood or any other light material.

214. *Trunnion Frame.*—I have before alluded to a plan by which I protect the trunnions on which the cylinder swings from the influence of heat; I will now explain this.

The cylinder of my engines does not hang, as ordinary oscillating cylinders do, upon gudgeons through which the steam passes on its way to and from the cylinder,—but upon a separate frame. The arrangements for the passage of the steam are all in the interior of the frame, and have no connection or contact with the trunnions,

so that these latter remain cold, or at least at a temperature which can have no injurious influence upon the friction; *i. e.* never exceeding 90° or 100° Fahr., even after the engine has been long at work. The great advantages of this arrangement I have already dwelt upon.

The trunnion frame is of cast iron, and has the form of an oblong parallelogram with rounded corners. It is shown in figs. 70 and 71, and also in section in figs. 56 and 57. The cylinder is bolted to it at *a* by the strong ears or snugs mentioned in Art. 207; and to compensate for the weakening of this part by the bolt-holes, it is strengthened at *c* by a little greater thickness of metal. It is also made stronger on the sides *b b*, from whence the trunnions spring.

215. *The Valve Apparatus.*—I come now to one of the most difficult parts of the description of my engine, viz. that of the valves and their apparatus.[23] They are shown in figures 72 to 95. The dimensions of all the parts, for the 10-horse engine, may be taken from the scales attached to the Plates; I shall only here mention sizes where great exactness is necessary.

The entire apparatus lies upon the upper cylinder cover, as may be seen in figs. 56, 57, and 72 to 75. It thus forms a sort of counterweight to the cylinder.

216. The upper cylinder cover is fixed by the flanch

[23] The Author has lately made a great improvement in his valve apparatus, by which the separate expansion box is rendered unnecessary, and the whole becomes much simplified. This will be described in a Supplement to his work, now publishing in Germany. I have much abbreviated the description in the Text, trusting that the detail of the Plates will be sufficient to explain all the parts to those who wish to examine them.—Tr.

d to the cylinder, with six or eight bolts, in the usual way, and has a projection ground slightly conical into the end of the cylinder. It has also another projection *c*, (figs. 72, 73, 74, 75,) upon which rest, first, the valve-box *a*,[24] and above that the expansion-box *b*.

e is the principal face, upon which the valve slides: it is shown in fig. 76. *f* is the opening to the upper end of the cylinder, *g* that leading to the lower end, and *h* the eduction opening. As this is the face upon which the valve works, the cover must be made of good hard iron, or, which is perhaps better, this face must be cast separately of such material, and fastened on. It must, in either case, be well faced and smoothly ground. The area of each opening should be equal to $\frac{1}{25}$ the area of the cylinder, and the breadth I usually make $\frac{1}{4}$ the length. For the 10-horse engine shown in the Plates, the openings are 3 inches long and $\frac{3}{4}$ of an inch wide. The bars between them must be about $\frac{1}{8}$ in. wider than the openings themselves: this is important, but is often neglected, and the consequence is that one port is sometimes opened before the opposite one is closed, allowing the steam to blow through, which with high-pressure steam would cause great loss. The channels *f* and *g*, leading to the cylinder, must preserve through their whole length the dimensions of the ports in the face, and must be free from sharp angles. The ends of the face are lowered a little, as shown at *r r*, that the slide may retain a good bearing on the projecting part of the

[24] *Steurungs-oder Schieberbüchse.* By some mechanics, these parts of the engine are called *nozzles*, a corruption of *nose-holes; i.e.* I suppose, the holes through which the cylinder may be said to breathe. I have retained, however, the simple translation of the original word.—Tr.

face, and may have liberty to push off any extraneous particles of dirt, &c., getting upon it.

217. The centre or eduction opening *h*, continues through the body of the cover, and ends in a cylindrical channel *k*, one-fourth the cylinder's diameter, and concentric with the axis upon which the cylinder swings. The curving of this channel should be as gentle as possible, all sharp angles being avoided. Its end is bored out to receive the conical stuffing-plug *l* of the eduction-pipe *m*. This plug is of brass, and furnished with a packing of thin hempen threads, the body of the plug being roughened where the packing is laid round, to hold the hemp without slipping. The plug is pressed into its seat by an oval plate *o*, which turns loose on a shoulder of the plug, and is fastened to the body of the cylinder cover by eye-bolts and snugs *p* and *n*: the eye-bolts are square, and are partly let into the metal of the cover, that they and the oval plate *o* may turn with it, while the plug remains still. It does not require to be screwed very tight, as the pressure of the escaping steam is not great.

The plug *l* is soldered to the eduction-tube *m*, which bends downwards, and increases gradually in size to one-half the diameter of the cylinder. It must be provided with a screw flanch, which may be loosened when it is required to examine the packing of the plug, and sufficient room should be left for the plug to be withdrawn. The arrangement of the eduction-tube is best seen in figs. 56 and 57, where 4 is the plug, 5 the first bend of the tube, 6 its screw flanch, and 7 the continuation of the enlarged tube, dividing into two branches, 8 8,

to miss the crank-shaft; 9 and 10 are two more screw flanches, connected to two pipes 11 and 12: these open again into one common pipe 13, by which the steam is carried away. 14 is a bulb upon this last pipe to collect the condensed water, and 15 a small tube through which it runs off.

218. The slide, or valve (*Schieber*), is shown in figs. 74, 75, 78, 79, 80, 81, 82. It is cast of a mixture of seven parts copper and one part tin; a composition which gives little friction upon hard cast iron, and is subject to but little wear. The dimensions will be found from the figures: the length is in all cases equal to twice the breadth of an opening added to three times that of an intermediate bar. The cavity on the under surface of the slide is semicircular,[25] and its length equal to twice the breadth of an opening, *plus* that of one bar.

The lower or slide-box *a* (figs. 72, 73, 74, 75) lies over the valve, being made tight to the cylinder cover with a lead packing at *i*. This box is high enough to allow the steam to pass freely over the top of the slide. On one side of the slide-box is the stuffing-box *t*, figs. 72 and 74, for the valve-rod *u*. It is constructed on the usual plan.

The valve-rod is not fastened directly to the valve, but to a square iron frame which drops over it, as shown in figs. 74, 75, 78, 79. This makes a firm connection between the valve and its rod, but at the same time allows of as much looseness as is necessary for the valve to adapt itself accurately to the face on which it

[25] It is sometimes made with square corners; but this is injudicious. Sharp angles should be carefully avoided in all steam passages.

slides, without being bound by the position of the rod in the stuffing-box. The frame is shown alone in fig. 78; the ends *c b* are thicker than the sides *a a*, for the purpose of gaining strength where attachments are made. At the top of the valve frame is fixed a bridge *d*, (fig. 78,) carrying two hard steel projections or snugs 2 and 4, (see also figs. 74 and 75,) the object of which is to catch against a pin *z*, projecting downwards from the expansion slide in the box above, and thereby, as the valve moves, to cut off the steam at the proper instant of time.

The valve is provided with two springs (as shown at *v v* in figs. 74 and 75), pressing against the top of the box, which should be smoothed to facilitate their action. The best material for the springs is sheet brass, hammered as hard as possible: steel springs soon rust, and do not retain their elasticity so long as brass ones.

219. The machinery for moving the valve is very simple; it is worked by the motion of the cylinder, without any eccentric, and contains only four joints. It is shown in fig. 88, which is a view of the valve apparatus, &c., looking from above. The valve-rod *d* is connected with a cross-head *e* by two nuts, one on each side: this mode of attachment gives great facility for adjusting the valve, and is much more simple and more easily made than a cutter. The cross-head is connected at each end to side-rods *f f*, which are jointed to gudgeons *l*, *m*, fixed by the brackets 18, (fig. 57,) to the cross bridge lying over the entablature box. The side-rods *f f* are prolonged beyond these gudgeons to *h h*, (fig. 88,) where they carry cast iron balls to act as

balance-weights for the cross-head and valve-rod, and to relieve the stuffing-box from unequal pressure. All the joints of this machinery should be made of steel, and hardened.[26]

Figs. 93, 94, and 95, will explain without further description how the slide-valve is worked by the oscillation of the cylinder.

220. Upon the lower or valve-box is fixed a separate and upper one for the expansion slide. This is shown in figs. 72, 73, 74, 75, at *b*. The top of the lower box serves as a face for the expansion slide, and must therefore be made of hard cast iron, and planed accordingly. It is shown in fig. 77, and has three holes, marked *a*, *b*, and *c*: *a* is the one through which the steam passes from the upper to the lower box; it is the same length as the ports in the lower valve face, but only half the breadth: it is widened out a little underneath, as seen at *w*, fig. 74.

The expansion slide *y* is of the same metal as the principal valve, and has an opening at *x*, corresponding with that above described, so that when these two openings come together, the steam flows from the upper box into the lower one: *z* is a hard steel pin, attached by a screw and nut to the expansion slide, and projecting downwards through the square opening *b*, fig. 77 (or 1, fig. 74), into the lower box: by this pin the expansion slide is made to act through the motion of the principal slide below. The

[26] The Author's method of working the valves by the motion of the cylinder is certainly very simple, but it must be recollected that he loses the advantage of the *lead* which may be given to the slide by the eccentric motion, and also the power which it gives of expanding to a certain extent by the valve alone. Moreover, by the Author's arrangement the engine cannot be *reversed;* it will move only in the direction shown by the arrows, figs. 54 and 56.—Tr.

slide must be perfectly ground upon its face,[27] and must always keep the square opening *b* (fig. 77) closed steam-tight. It should be provided with two springs similar to those of the lower valve.

I have, in one or two of my engines, given the expansion slide a separate rod and stuffing-box, and caused it to be moved by an external apparatus. This arrangement is shown in figs. 91 and 92.

221. It remains to describe the manner in which the steam is brought to the valves.

The steam-pipe, which is $\frac{1}{5}$th the diameter of the cylinder, is brought from the back of the engine, over the top of the entablature, as shown at 9′, fig. 57; it then bends downwards at the front, and is connected by a flanch 10′, to a horizontal tube 11′, (lying exactly in the swing axis,) and passing by a stuffing-box 12′, into the body of the cylinder cover. In fig. 88, where these arrangements are also shown, the steam-pipe is marked *i*, the flanch *k*, the horizontal piece *l*, and the stuffing-box *m*. The latter is of the common construction, and the pipe passing through it must be made of strong brass, and carefully turned; it may be $\frac{1}{6}$th of the diameter of the cylinder in the clear, and must be long enough for the gland of the stuffing-box to slide outwards upon it when it is wished to renew the packing. In order that the great pressure of the steam may not force this pipe outwards, it may butt against the frame, as shown at 13′, fig. 57: a small gudgeon of hard wood may be interposed to prevent the communication of

[27] Pumice-stone (*Bimstein*) is better than common emery (*Schmirgel*), for grinding these faces; the particles of the latter are apt to set fast in the brass, and eventually to increase considerably the abrasion.

heat from the pipe to the frame, and a contrivance may easily be adopted for adjusting this, should the friction wear it away.

The further passage of the steam is seen distinctly in fig. 75. It passes from the pipe last mentioned up a channel marked 5, left in the thickness of metal of the cylinder cover *c* and valve-box *a*, and finally opens into the expansion-box *b*. The channel should be at least of the same area as the pipe 11′, and all its angles should be rounded.

222. In order to show more clearly the operation of the valve apparatus, I have given in fig. 90 a set of diagrams taken in eight different positions of the crank. The steam passes from the upper or expansion-box *b* into the lower or slide-box by the opening *w*, when the position of the expansion slide leaves this opening free: it will be seen, however, that the snugs 2 and 4, on the main valve, catch and move the expansion slide so as to close the opening *w* after about one-third of the stroke is completed, the steam already admitted being allowed to expand during the remainder.

A reference to Nos. 3 and 7 of fig. 90 will show that the travel of the valve is a little greater than is absolutely necessary: the object of this is to give the valve somewhat greater velocity at the time it is in the middle of its stroke (Nos. 1 and 5), that the eduction passages may be opened with the greatest possible rapidity; for it is very important, as I have already had occasion to remark, that the steam should discharge itself as freely as possible. The trifling contraction of the eduction opening in Nos. 3 and 7 is of no great consequence compared with the

advantage of a freer exit at the commencement of the stroke.

223. The use of the opening *c* (fig. 77) in the cover of the valve-box, or bottom of the expansion-box, has not yet been explained. It is a sort of by-pass, to allow the steam to travel freely from the upper into the lower box when it is not wished to expand, *i. e.* when the steam is required to act upon the piston at full pressure during the whole stroke. Of course, however, this opening must be closed when expansion *is* used; and fig. 85 shows an apparatus by which it may be opened or closed at pleasure: *a* is the opening; *b* a slide which covers it; *c* a rod holding upon the slide by a rake-like end *e*, and passing outwards through a stuffing-box *d*. Certain details of the apparatus are shown in figs. 86 and 87, and the whole is seen in its place in fig. 56. The outer end of the rod is attached by a link to a lever 15′, which moves in a guide 16′ and has a handle at its lower end.

This passage should always be thrown open when the engine is started, and kept open for some little time, till the cylinder and other parts have become warmed. It may also be opened, either wholly or partially, during the working of the engine, if a temporary increase of power is required.

224. *The Governor.*—This is of the usual construction, and stands above the entablature of the framing, as shown at I in figs. 54, 55. The reason I have chosen this position is, that it gives the engine a finished and handsome appearance, and the governor is out of the way.

It has a steel foot working in a box *a* (fig. 89) of the same metal, which is fixed to a cross-beam *c*. This latter is in one piece with the bridge *b*, supporting the neck of the governor, as well as the prop *d* for the centre of the lever *e*: *f* is the rod which works the throttle-valve; it is provided with a screw, by which it may be lengthened or shortened for adjustment.

The governor is worked by a strap *q* (figs. 54, 55), running from a pulley *r* on the fly-wheel shaft, over guide-rollers *t*, to the pulley *s* on the governor.

225. The *throttle-valve* is of the usual construction, exactly as used for low-pressure engines. It is true that this kind of valve cannot be made steam-tight; but this is not necessary, for the governor is not intended to shut the steam entirely off, only to diminish its flow. Such a valve turns easily, and therefore does not require much power in the governor.

The rod of the valve passes through a stuffing-box, and is provided with a lever, to which the governing-rod is so attached that the effective length of the lever may be lengthened or shortened, and the valve thereby be made more or less sensitive, at pleasure.

I would give a strong warning against the use of *cocks* for this purpose. They are especially unfit for such a duty.

I always make a provision for shutting off the steam, independently of the throttle-valve, by placing a stop-cock, or valve (which is better), between the throttle-valve and the boiler. This is necessary, partly in order to leave the governor gearing undisturbed, and partly to insure the steam being entirely shut off, which cannot be done by the

throttle-valve alone, and which is necessary for several reasons that need not here be repeated.

226. *Connection between the Piston-rod and Crank.*—This consists of a single connecting joint between the piston-rod and crank-pin, in two parts, bolted together, with brasses, of the usual construction. It is shown fully in figs. 54, 55, 56, 57. I place pieces of hard wood between the two parts of the joint piece, to enable the nuts to be screwed up tight without throwing too much friction on the pin.

When the engine is very large, and the cylinder very heavy, it may be advisable to add guides to the piston-rod. Fig. 110 shows an arrangement for this. The guiding surfaces should be of hard polished wood, and as wide as possible. I have never, however, hitherto found such guides necessary.

227. The *crank* F (figs. 54 to 57) is of cast iron; its length for the 10-horse engine is 1 foot, the stroke of the piston being 2 feet.

The *crank-shaft* G is circular, 6 inches in diameter. It has a collar *l l* on each side of the bearing, to prevent lateral motion, which would be injurious to the working of an oscillating engine: this precaution is peculiarly necessary where the shaft drives bevel-wheels, which always cause lateral thrust.

228. The *fly-wheel* H is of the ordinary construction:[28]

[28] Attempts have been made to introduce mechanism to supersede the fly-wheel. Such contrivances are usually complicated and expensive, and cause much loss by friction.

for the 10-horse engine, it is 10 feet diameter, and weighs from 16 to 20 cwts. When it is large, it is convenient to make it in several pieces. For engines of 1 to 20-horse power, four arms will suffice; larger wheels should have six arms.

The formula given by Murray for the weight of the fly-wheel is as follows:

Let H = number of horse power of the engine.

V = velocity of fly-wheel rim, in feet per second.

W = weight in cwts.

Then $W = \frac{2000\,H}{V^2}$.

I believe, however, that for common cases this weight is heavier than is required, and may be reduced one-third, if not one-half. I have reduced it one-half in some of my engines, and have found no perceptible degree of irregularity. I would recommend that the co-efficient in the above formula should be made variable according to the purpose for which the engine is required, in the following manner:

(*a.*) For purposes in which no great degree of regularity is necessary, such as corn-mills, oil-mills, saw-mills, pumping, and so on, let the number be 1000 instead of 2000.

(*b.*) Where regularity is of more importance, as for example, for spinning the coarser threads, let the number be 1500.

(*c.*) Where very great regularity is required, as for spinning the finest threads, the co-efficient may remain 2000.[29]

[29] The formula above given for the weight of the fly-wheel is not based upon a correct principle; it should contain another quantity. The subject

229. *Condenser.*—I have already spoken of the adaptation of a simple condenser, under certain circumstances, to the high-pressure engine.

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has been well discussed by Poncelet, Morin, Moseley, Hann, and others. The following are the principal features of their investigations.

The object of the fly-wheel is not to produce a motion perfectly uniform, that is impossible, but to give a degree of regularity as nearly approaching uniformity as suffices for the work to be done. There are two points in the revolution where the velocity will be at a maximum, and two where it will be at a minimum: the object then is to make the difference between these two velocities so small that the irregularity will be of no consequence in practice.

Now let P = pressure on piston in ℔s. (assumed uniform throughout the stroke).

g = force of gravity = $32\frac{1}{6}$.

r = radius of crank in feet.

W = weight of fly-wheel rim in ℔s.

V = *mean* velocity of fly-wheel rim, or velocity at the instant when the crank passes the dead point, in feet per second.

Then the velocity v at any other point, corresponding to any angle θ passed over by the crank *from* the dead point, is found by the following formula; that is, neglecting the disturbing effect of any mass in the engine other than the fly-wheel rim.

$$v^2 = V^2 + \frac{2g\,Pr}{W}\left(\text{Vers.}\,\theta - \frac{2\,\theta}{\pi}\right).$$

It is easily found that the maximum velocity is when θ = about 140°, and the minimum when θ = about 40°; wherefore, reducing, we have

$$\text{Max. vel.} = V^2 + 13\,\frac{P\,r}{W}.$$

$$\text{Min. vel.} = V^2 - 13\,\frac{P\,r}{W}.$$

Now suppose we wish our machinery to run with such a degree of uniformity that its maximum velocity shall only be $\frac{1}{n}$th greater than its minimum velocity, or, which is the same thing, that the velocity shall never deviate more than $\frac{1}{2\,n}$th from the mean value V. Then by a simple reduction from the above formulæ, we may find the weight W necessary to produce such a degree of uniformity, thus:

$$W = 13\,\frac{P\,r\,n}{V^2}.$$

An apparatus of this kind is shown in figs. 96 and 97. *a* is the eduction-pipe of the engine; *b* the condenser, a pipe of sheet copper, the same diameter as the eduction-pipe, and about twice the length of the stroke of the engine. It lies in a cistern *c*, supplied with water from a pipe *k*; *i* is a sieve to prevent any particles of dirt getting into the part of the cistern from which the injection water is drawn, and *h* is an overflow by which the waste runs off; *l* is an emptying cock. The condenser is laid on an incline; the lower end projects out of the

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Or we may give this a more convenient shape for practice, thus:

Let H = Horse power of engine.
R = Mean radius of fly-wheel rim.
N = Number of revolutions per minute.

Then in round numbers,

$$\text{Weight in cwts.} = \frac{90{,}000\,\mathrm{H}\,n}{\mathrm{R}^2\,\mathrm{N}^3}.$$

It only remains to say something of the value of *n*, or the degree of irregularity which may be admitted without inconvenience in practice. Morin, in his 'Aide-Mémoire de Mécanique Pratique,' gives three different classes of machinery, similar to those marked *a*, *b*, and *c* in the text, for which different degrees of uniformity of motion are required. For the first (*a*), he states that n should be $= 20$ to 25; for the second, $n = 35$ to 50; for the third, $n = 50$ to 60.

Or, substituting, we may adopt the following simple approximate rules, the weight being given in cwts. as before.

$$\text{For class } (a),\ \mathrm{W} = \frac{2{,}000{,}000\,\mathrm{H}}{\mathrm{R}^2\,\mathrm{N}^3}.$$

$$\text{For class } (b),\ \mathrm{W} = \frac{4{,}000{,}000\,\mathrm{H}}{\mathrm{R}^2\,\mathrm{N}^3}.$$

$$\text{For class } (c),\ \mathrm{W} = \frac{5{,}000{,}000\,\mathrm{H}}{\mathrm{R}^2\,\mathrm{N}^3}.$$

Example.—Suppose a certain engine to be 10-horse power, with a fly-wheel about 5 feet radius, and making 50 revolutions per minute. What should be the weight of the fly-wheel rim, supposing the engine is intended to work machinery under class *c*?

$$\text{Here } \mathrm{W} = \frac{5{,}000{,}000 \times 10}{(5)^2 \times (50)^3} = 16 \text{ cwts.—Answer.——Tr.}$$

cistern into a box *e*, and is furnished with a hanging or flap-valve *d*, opening outwards. *m* is a small pipe, in which is fixed the injection-cock *n*, turned by the key *o*. The pipe is bent in the interior of the condenser, as at *a*, fig. 97, and has a mouth-piece *b*, so shaped as to spread the jet of water.

The action of the condenser is as follows. At the moment the eduction passage is opened to the cylinder, the steam, having a pressure considerably above that of the atmosphere, rushes through the pipes, stops the injection, and blows the water and air collected in the condenser out at the valve *d*, into the vessel *e*. This, however, is but the work of a moment; the valve immediately falls, the jet of water again enters, and the steam is condensed. The air and vapour pass away from the vessel *e* by the pipe *f*, the water by the pipe *g*.

I have only yet had opportunity of applying this condenser to two engines, both being single-acting, and used for pumping water. No barometer can be used with it for obvious reasons, and therefore it is difficult to tell exactly the state of the vacuum. The best proof, however, of the efficiency of the apparatus is, that the engines, even when they are in their most powerful and quickest action, will be stopped by simply closing the injection-cock.

This condenser was one of my earliest inventions for the steam engine: it has been ascribed to others, but I made known a description of it sixteen years ago.[30]

[30] That is, about 1826.—Tr.

PART IV.

GENERAL REMARKS

GENERAL REMARKS.

ON THE CONSUMPTION OF FUEL.

230. I will now proceed to give some particulars respecting the economical properties of my engines. This is, of course, a point which has much interested me; I have spared no pains to gather correct observations upon it, and I will lay before the reader the results of the investigations and experiments I have made. I have asserted that my improvements tend to produce economy of fuel: this is one of the great ends I have in view; after safety, the principal one. I am now to prove my assertion, which I shall do in the most conclusive way, namely, by showing the actual consumption of fuel by engines constructed on the improved principles I have laid down.

231. In estimating the power of the engines tried, I have had no opportunity of using Prony's brake: I have, however, resorted to other methods not less satisfactory. In some cases a very direct means was at hand, inasmuch as several of the machines driven by the engines were previously worked by horses. Proofs of this kind, although perhaps not so scientific as those drawn from dynamometric experiments, are more practical, and tell home to the minds of those most interested in the subject, namely, the public who use the engines. The estimations

thus obtained are not the result of experiments made over short spaces of time, but have been derived from long-continued observation of the working of the engines, and are therefore more free from chance of error. I hope my readers will be convinced, when I lay the particulars before them, that I have endeavoured to form my estimates impartially, and not to distort them in favour of my engines.

232. I will first instance an engine which I had for two years under my own daily observation, in an iron foundry and machine manufactory in which I was a partner.

The engine was nominally 3-horse power, and had a form like that sometimes called Maudslay's portable engine, but of course without the parts belonging to the condensation. The cylinder was 4½ inches in diameter in the clear, and had a stroke of 1 foot, and the engine was so light that, without the fly-wheel, it could be carried by two men. Its usual velocity was from 70 to 80 revolutions in a minute, dependent on the work it had to do.

It drove the following machinery, viz.

(*a.*) Six lathes; three small and three large. One of these had a 7-inch spindle; and they had often heavy work upon them while all the under-mentioned machinery was in action.

(*b.*) One grindstone.

(*c.*) One cylinder blowing machine for six smithy fires. This drew in regularly 200 to 220 cubic feet of air per minute at atmospheric pressure, and delivered it to the fires at a pressure of ½ ℔. per square inch.

(*d.*) Also, on casting days, a large blowing machine for the foundry, which drew in 700 cubic feet of air

per minute, and blew it out again under a mean pressure of $\frac{5}{8}$ lb. per square inch.

The latter alone required, before the steam engine was erected, the power of two large and strong horses, which were often foaming with perspiration during a work of only four or five hours. The power required to work the small blowing machine may be reckoned by the proportionate quantity of air drawn in; remembering, however, that the small machine had a greater relative amount of friction and prejudicial resistance to overcome than the large one. The blowing engine at the Royal Iron Foundry in Berlin, which only draws in 960 cubic feet per minute, and delivers it at $\frac{5}{8}$ lb. pressure, has been estimated at 11 or 12-horse power.

When therefore all the above work is considered, I do not think I estimate the power of the engine too high at 4-horse power.

Now with all this work upon it, it required only in fourteen hours $4\frac{1}{2}$ Mecklenburg bushels (*Scheffel*) of Newcastle small coal, weighing in a wet state (*im nassen Zustande*) 340 lbs., or dry at most 300 lbs. This gives the consumption of coal

$$\frac{300}{14 \times 4} = 5{\cdot}3 \text{ lbs.}$$

per horse power per hour.[1]

I think this must be allowed to be an extraordinarily economical result for so small an engine.

233. The next instance I will give is an engine of 10-horse power, exactly similar to the one drawn in the

[1] Equal to 35,000,000 *duty*, according to the Cornish method of calculation.—Tr.

Plates to this work: the cylinder was 8 inches diameter, the stroke 2 feet, and it made 50 revolutions in a minute.

It was in a paper-mill, and drove two large machines (*Holländer*), a large pump, some presses, and a new machine of my own invention. Previously to the erection of the engine, four strong horses were required to work one of the two machines first named, and when engine power was applied, the machine worked up one-half more material in two-thirds of the time, giving nearly double the amount of work done by the horses. When therefore the pump, the presses, and the additional machine are also considered, I cannot think I rate the engine too high at 10-horse power; it was in reality above 12.

The fuel used was pressed turf (*Tradetorf*), which I have found by calorimetric experiments to stand in the ratio of 0·85 to 2 compared with coal, as regards its heat-giving power. The consumption by the engine was, when reduced according to this proportion, equivalent to between 6 and 7 ℔s. of coal per horse power per hour.[2]

234. The engine above mentioned was afterwards removed to an oil-mill, where it crushed 100 to 110 Mecklenburg bushels (*Scheffel*) of seed in a day of 14 or 15 hours: the engine was, however, not then exerting its full power. This work was formerly driven by four horses, of the largest and strongest race that could be found in Mecklenburg; each horse weighed 1100 to 1200 ℔s., and might certainly be reckoned equal to 1½ or 2-horse power, according to the usual steam engine calculation. These horses were changed every three hours, and during their work were always very wet with per-

[2] *I. e.* about 30 millions duty.—Tr.

spiration; and yet they could only bruise 60 or at most 70 bushels of seed. The engine, moreover, drove the machinery with one-fourth greater velocity, and I therefore may reckon the power exerted at 8 horses, without exaggerating in favour of the engine.

The consumption of fuel is between 800 and 900 lbs. of coal in fifteen hours, which is equivalent to about 7 lbs. per horse power per hour, as before.

235. An engine of very small size, used by me for driving three lathes, a grindstone, and a blowing machine for two smithy fires, required 9 to 10 lbs. of coal per horse power per hour.[3]

236. An engine of 2-horse power, erected by me for the purpose of draining a turf moor at Dobberan, and in which the steam is cut off at one-half the stroke, lifts 30 to 36 million pounds of water 1 foot high by the consumption of an English bushel of coal,[4]—a very high result for so small an engine.

237. One of my latest engines, erected in a wool-spinning factory at Malchow, requires 5·1 lbs. of coal per horse power per hour. It is an 8-horse engine, but is only working up to 6-horse power.

238. The last example I will mention is an engine of 30-horse power, erected by me in the Ducal cloth factory at Plau. Its construction is similar to the normal form given in the Plates: the cylinder is $13\frac{1}{4}$ inches diameter,

[3] About 26 millions duty.—Tr.

[4] Equal to 5 or 6 lbs. per horse power per hour.—Tr.

the stroke is 3 feet, and the number of revolutions in one minute 36. The boiler is that shown in fig. 52, having fifty-six copper tubes, each 5 feet 4 inches long, 4 inches external diameter, and $\frac{1}{10}$th of an inch thickness of metal; the surface of fire-grate is 18 feet.

The engine drives the whole machinery of a large woollen-cloth factory, consisting of thirty-six machines of various kinds, with shafting and connecting apparatus, disposed over three floors of the building.[5] I have estimated the power, partly by comparison with other machinery of the same kind driven by horses, and partly by the best authorities I could obtain, and the best judgment I could form. The engine will work easily all the machinery at once, with a pressure in the boilers of 90 to 105 ℔s.; and I estimate the work then to be equal to 34-horse power.

The fuel used is a light unpressed turf (*Stechtorf*), containing much earthy matter, and filling the fire-grate with ashes, so that constant raking is necessary. The consumption, with all the work upon the engine, has been found 5088 ℔s. of such turf in a day of twelve hours, which is 12·4 ℔s. per horse power per hour.

Now when it is considered that the turf was of very inferior quality, and moreover not perfectly dry,—and that the heating power of a much better kind has been found to be 0·425 that of coal,—we may fairly assume that the calorific power of this fuel is to that of Newcastle coal as about 1 to 3, which makes the consumption equivalent to 4·1 ℔s. of coal per horse power per hour.[6]

[5] A list of these machines is given by the Author, with the estimated power required by each. I have seen the manufactory, and do not think the estimate over-rated.—Tr.

[6] Or about 45 millions duty.—Tr.

The facts in the above statement were ascertained with great exactness in presence of a commission appointed by Government to examine the engine.[7]

[7] It may not be irrelevant here to apply some of the known principles of calculation to the Author's engines, in order to check the correctness of the statements relative to their power and the experimental results of their working. We may be able thus to show that these statements contain nothing but what is reasonable and probable.

As the most convenient example, we may take the normal engine of 10-horse power; and calculate, by ordinary rules, what ought to be the pressure of the steam in the cylinder, the quantity of water evaporated, and the weight of fuel used.

The cylinder is 8 inches diameter, = 50 in. area, the stroke is 2 feet, and the engine makes 50 revolutions per minute; the mean velocity of the piston is therefore 200 feet per minute. Hence we have

$$\frac{33000 \times 10}{200 \times 50} = 33 \text{ lbs.}$$

for the mean *effective* pressure per square inch of the piston. If we add to this 20 lbs. (a very ample allowance) for back pressure and friction, we have the *total* mean pressure on the piston = 53 lbs.

Now if we suppose the steam to expand by Marriotte's law, and neglect the effect of the clearance space, (suppositions near enough for our present purpose,) the *mean pressure* is

$$= P\frac{l}{L}\left(1 + \log._\epsilon \frac{L}{l}\right);$$

where P = pressure at which the steam is admitted; L = total length of stroke; and l = length of that portion of the stroke during which the steam is admitted. In the present example, L = 2 feet, and l = 8 inches; wherefore, solving the equation for P (the mean pressure being known), we have

$$P = \frac{3 \times 52}{1 + \log. 3} = 75 \text{ lbs., or 5 atmospheres.}$$

Therefore, since the Author professes to work up to 8 atmospheres in the boiler, we have no difficulty in conceiving the *power* of the engine stated, in proportion to the size of cylinder, to be reasonable and true.

We will next proceed to calculate the quantity of water evaporated. The length of stroke during which the steam is admitted is 8 inches, and this, multiplied by 50, the area of the cylinder, gives a volume of 400 inches; to which adding 100 for clearance and waste, (also a very ample allowance,) we have 500 cubic inches of steam at a pressure of 75 lbs. used each stroke. But the relative volume of steam at this density is 381; whence we have

239. I can bear testimony to the truth of Oliver Evans's assertion, that the consumption of fuel in high-pressure engines does not increase proportionately with the work done. The engine mentioned in Art. 232 has afforded me ample opportunity of proving this; for on the days when the large blowing machine was attached, which quite doubled the power, the consumption of fuel was not near doubled thereby.

240. The method of firing is very important with high-pressure engines. The heat should be kept as regular as possible; and for this purpose the fire should be fed frequently, and with small quantities at a time, taking

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$\frac{500}{381} = 1{\cdot}31$ cubic inch of water used each stroke; which, multiplied by 100 single strokes per minute, gives 131 cubic inches, or 4·7 lbs. of water evaporated per minute, = about 280 lbs. per hour.

Supposing, then, 1 lb. of coal to evaporate 7 lbs. of water, (a very moderate estimate,) the engine will require 40 lbs. of coal to evaporate the above quantity, or 4 lbs. per horse power per hour.

We see thus that the economical results stated by the Author are only what may be reasonably expected from the given conditions in the engine.

We may further examine another point, which is particularly dwelt upon by the Author, namely, the economical value of the *waste steam* blowing out from the engine.

We have estimated above that there are 4·7 lbs. of steam passing through the engine per minute. Now it is well ascertained that 1 lb. of steam, at whatever temperature, (the sum of the latent and sensible heats being constant, according to Watt's law,) will, by condensing into water at 212°, give out about 1000 *units of heat*, i.e. 1000 times as much as will heat 1 lb. of water 1°. Hence the quantity of heat proceeding from the engine is = 4700 units per minute.

Suppose, then, only *one-half* of this to be made available for useful purposes, and the other half wasted,—blown off into the air, &c.,—we have still a quantity of heat saved from this 10-horse engine which will raise nearly 100 gallons of water per hour from 62° to boiling-point, or will heat in the same time about 250,000 cubic feet of air from 30° to 60°.—Tr.

care, however, not to admit more cold air at the doors than can be avoided. When coal is used for fuel, it should be broken in small pieces, and spread in a thin layer, which will cause less smoke than when put on in massive quantities.[8] It is always advantageous to give the stoker plenty to do. If the coals fall through the bars unburnt, they should be put afresh on the fire.

ON THE DIMENSIONS AND PROPORTIONS OF THE ENGINE.

241. I have already spoken in many places of the dimensions of various parts of the engine; I will now give some rules for the general proportions and dimensions, which it would have been inconvenient to introduce elsewhere.

The engine given in the Plates as a normal example is of 10-horse power: the cylinder is 8 inches diameter; length of the stroke 2 feet; number of revolutions 50 in a minute; diameter of piston-rod 2 inches; height of packing of the piston 4 inches; diameter of the steam-pipe 2 inches, and of the eduction-pipe $3\frac{1}{2}$ inches;[9] dimensions of the steam and eduction ports 3 inches by $\frac{3}{4}$. All other dimensions may be ascertained from the scales attached.

I take the diameter of the cylinder for the basis of all calculations of the dimensions of the engine; and this having been fixed (by the rule in Art. 242), the linear proportions of the parts to each other will remain the

[8] These are exactly the directions given by Smeaton and Watt, and practised in Cornwall (see 'Appendix G. to Tredgold,' Art. 135). I think it probable, however, that the Author was not acquainted with this fact.—Tr.

[9] These dimensions differ a little from those stated in Arts. 217–221.—Tr.

same as in the normal engine, with the following exceptions:

(*a.*) The packing of the piston should never exceed 6 inches in depth for the largest engines. The length of the cylinder will depend upon this, and where it becomes shorter than the proportion of the normal engine, the difference may be added to the length of the stuffing-box, or to the interval between this and the crank-pin.

(*b.*) The packing of the stuffing-box for the piston-rod should not exceed 6 inches in depth.

(*c.*) The section of the fly-wheel rim, and strength of the arms, must be determined by the weight, as calculated by the proper formula (see Art. 228). The diameter may remain as drawn.

(*d.*) With small engines under 6-horse power the stroke may be somewhat lengthened; but for the largest I would not make it longer than 4 feet. The framing will of course require alteration when the stroke is altered. Very small engines may be given a simpler form, which I shall hereafter show.

242. The calculation of the diameter of the cylinder is very simple. I make it *four-ninths the diameter of the cylinder of a Boulton and Watt condensing engine of the same power*, according to the ordinary Tables.[10]

243. The number of revolutions per minute should be such that the mean velocity of the piston may be—

[10] I find that the following simple rules answer for the Author's engines:
The *horse power* = $\frac{1}{6}$ the square of the diameter of the cylinder in inches.
The *diameter of the cylinder* = the square root of 6 times the horse power.
When the horse power is above 30, or the cylinder above 13 inches, the co-efficient 6 may be changed to be $\frac{11}{2}$.—Tr.

For engines under	10 H. P.,	180 ft. per minute.
„ from	10 to 50 „	200	„
„	50 to 100 „	240	„

These rules may, however, be departed from if circumstances require a particular velocity to be given to the crank-shaft. A small high-pressure engine may move 240 feet per minute without the disadvantage that would arise to a condensing engine under such circumstances.

244. The quantity of water required to be furnished by the feed-pump may be calculated by the following formula, which my experience has shown to be satisfactory.

Let A = area of the steam cylinder, and L = length of stroke, both in inches. Then the number of cubic inches of water required each stroke is

$$= \frac{A\,L}{262}.$$

This supposes the steam to be 8 times the density of that at atmospheric pressure (= about 9 atmospheres' elasticity), and cut off at one-third the stroke: it allows nearly 20 per cent. extra supply for chance of waste, &c.

ON THE APPLICATION OF THE ENGINE TO MACHINERY OF VARIOUS KINDS.

245. I have already stated that I consider it injudicious to adhere implicitly to one fixed form of engine. To use one invariable construction, be the object ever so different, or the circumstances under which it works ever so various, argues a poverty of ideas, absence of talent, and want of experience, very unworthy of the high position which the Engineer is supposed to occupy in the scientific world. There have been *fashions* in the form of an engine, just as

in the cut of a coat, and these have been adopted often at the expense of simplicity. It is easy to understand that a fixed form of engine cannot be applicable to all required purposes, if the application is to be made in the simplest possible manner, and with the least possible loss of power. If a rotatory movement is required, a crank engine should be used;—if a reciprocating rectilinear motion is wanted, the reciprocating motion of the piston should be directly applied. Wherever the machine to be set in motion stands, it is certainly better, if possible, to apply the power directly upon this point, than to bring it from another situation by complicated connecting organs. The more connecting machinery, the more unnecessary first cost, and continual loss of power.

In all my designs I follow the rule, confirmed alike by experience and common sense, that the power of the piston must be applied as directly as possible upon the machines to be moved; and there are few cases, even in adaptation to existing arrangements, where this end may not be more or less satisfactorily attained. I shall proceed to show how I endeavour to effect this object, by descriptions of various combinations of the steam engine with machinery, illustrated by the figures in Plates XXII. to XXVIII.

As a general remark, however, I would observe, that for all works where the main driving shaft lies horizontally, and near the ground, the normal form hereinbefore described should be adhered to as the best construction. Where this shaft lies high, some of the other forms shown in the following descriptions may be adopted.

246. *Oscillating Engine with the Main Shaft above the Cylinder.*

Figs. 98 and 99 represent an engine where the piston-rod works upwards, instead of downwards as in the normal form. The fly-wheel shaft rests upon a frame *b*. The cylinder *c* hangs in a trunnion-frame *d*, constructed on the same principle as that already described. The valve apparatus may either be placed at the bottom of the cylinder or at the front or back, between the cylinder and the trunnion-frame. The connecting piece between the piston-rod and crank should be of a good length, in order to remove the swing centre as far as possible from the crank-shaft.

This form of engine is light and simple, and especially adapted to engines of small power.

Figs. 108 and 109 show a modification in which the trunnion-frame of the cylinder is removed, applicable to cases where the space is confined, and where it is preferred to let the steam pass through the trunnions.[11]

247. *Engine with a fixed Cylinder and Connecting-rod.*

Figs. 100 and 101 represent an engine adapted for cases in which the driving shaft lies very high. It has a fixed cylinder, the top of which projects above the foundation plate. The main shaft *c* may lie either upon the upper beams of the building or upon a bracket *d*, supported by columns *ef*, as shown in the figure. *g* and *h* are guides, with faces of hard wood, adjustable by set screws; they are attached to the columns by brackets *mn*. *op* is a slide with hardened faces, attached to the piston-rod *k*.

[11] The Author has contrived a very ingenious and effectual method of reducing the friction and wear in gudgeons so placed, working under high temperatures. This will be described in the Supplement now about to be published in Germany.—Tr.

I prefer slides to friction rollers, as the latter are more liable to get out of order, and run untrue.

For the attachment of the connecting-rod *l* to the piston-rod, I use a ball and socket joint, which is much easier to make than the ordinary strap and cutter joint used for such purposes, and works better, adapting itself to movement in any direction. It is shown more particularly in figs. 113, 114. *a* is the piston-rod, fastened by a cutter to the lower part of the socket of the joint; *b* is a hardened steel ball, fixed by the short rod *c* to the connecting rod *d*. The rod *c* plays through a hole in the upper part of the socket, as is seen in the figure.

248. *Engine for driving a Vertical Shaft.*

Fig. 102 represents a form of engine which I would recommend for giving motion to vertical shafts, such as for driving corn-mills. The steam cylinder here oscillates horizontally; it is bolted firmly to a strong cross piece *b* on the upright shaft *c*, which swings in the carriage *d*, and the step *e*. The piston-rod has a small guide *f*, which slides on two turned wrought iron rods *g*, attached to the cylinder at one end and to a connecting piece *h* at the other. *i* is an additional strut, to give firmness to the piece *h*. *k* is the connecting joint between the piston-rod and the crank-pin *l*, set in the spur-wheel *m*, which gives motion to the stones. This wheel is somewhat heavy, and acts as a light fly-wheel: a heavy fly is altogether unnecessary in a corn-mill, because the stones themselves act as such. The valve motion lies above the cylinder, as shown in the figures. *n n* are the channels to the cylinder. The valve-rod moves in a guide *s*, and is worked by a rod *r* from an eccentric *o*, on the shaft *p*,

turned by a small counter-crank *q*. *t* is the steam-pipe, turning in a stuffing-box *u*. *v* is the eduction-pipe, which is double, passing down each side of the cylinder, and joining in a stuffing-box and single pipe at *w*. The engine works in a room separated by the wall *x* from the mill-rooms *y*.

249. *Single-acting Pumping Engine.*

Fig. 103 represents the engine erected by me for lifting water at Dobberan Turf Moor, and referred to in Art. 236. In this I have used a beam, though it is by no means absolutely necessary. The cylinder *a* is constructed for single action, *i. e.* working by the descent of the piston only. The valve *b* is a slide, the construction of which is shown clearly by the sections, figs. 111 and 112. *g* is the beam, having upon the ends two arcs *m* and *n*, to which the piston and pump-rods are hung by strong straps (*Riemen*); and as the engine is but of the small power of 2 or 3 horses, these answer very well. *o* is the framing; *p* the pump, which is of copper, furnished with a cistern *q*, and run-off trough *r*: *s* is the pump-rod, and *e* the counterweight. *c* is the condenser, and *u* the feed-pump with its rod *t*. *v* is a catch-rod, to prevent the engine making too long a stroke either upwards or downwards.

The lower end of the cylinder is constantly open to the condenser, by a side pipe *d*. The steam acts upon the upper side of the piston, and is cut off at half its stroke by the valve moving into the position fig. 112; at the end of the stroke the valve takes the position fig. 111, the steam blows into the condenser, and a vacuum is soon formed above as well as below the piston; the counter-

weight then acts, and the engine performs its *out-door* stroke, at the end of which the valve is reversed, and the in-door stroke repeated as before.

The valve is moved by the plug-rod *f*; it has on one side two tappets *h* and *i*, which strike against the lever *k*, and so raise or lower the valve, and put the cylinder port in communication with either the boiler or the condenser. The lever-shaft carries also a smaller bent lever *l*, acted on by another tappet on the opposite side of the plug-rod, the object of which is to bring the valves at half stroke into the position fig. 112, thereby shutting off the supply of steam to the cylinder. This latter tappet is moveable, that any required degree of expansion may be used.

Figs. 104 and 105 represent a pumping engine of simpler form, the cylinder standing directly over the pump. This arrangement will be understood without description. The steam acts, of course, underneath instead of above the piston. The valves are worked by a tappet upon the piston-rod.

I saw a large engine on this simple construction belonging to the New River Water-Works Company, and working in Thames Street, London.[12]

250. *Arrangement for Marine Engines.*

Figures 106, 107, show an arrangement of oscillating engines for marine purposes. This is so simple, and takes, with its boiler, so little room, that it occupies scarcely one-fifth part of the capacity of the vessel;

[12] This construction was used in Cornwall by William Bull about 1790, and has been lately revived, both there and elsewhere. See 'Appendix G. to Tredgold,' Art. 50.—Tr.

whereas the ordinary low-pressure beam engines require nearly one-half. The figures will be understood without description.[13]

ON THE USE OF THE WASTE STEAM FROM THE ENGINE.

251. I have already mentioned, as one of the principal advantages of the high-pressure engine, the opportunity it gives of using the steam, after it has passed through the cylinders, for many purposes where heating is required: this advantage is often inestimable for large manufactories where spacious rooms have to be warmed, fluids to be heated, hot water to be in constant readiness, &c., &c. In such cases, if the steam can be properly applied, it may often be considered that the power of the engine is obtained for nothing, since as great a consumption of fuel would be required, were there no steam engine.[14]

This advantage has been too much neglected. Many mechanists with whom I have spoken have either not thought of it at all, or thought too lightly of it. I have put it in practice successfully for twenty years. In one of my early manufactories, the whole establishment was warmed in winter, and in summer the operation of drying wood was performed in this way. In a paper manufactory, the waste steam was applied to many purposes, one of which alone formerly required one-fourth as much fuel as was afterwards used for the whole engine. In the Ducal cloth factory at Plau, three large stories are warmed, water heated, certain machines supplied with steam, and other

[13] Let it not be forgotten that this was written nearly ten years ago.—Tr.

[14] See note on page 279.—Tr.

operations requiring heat are effected, all with the waste steam from the engine.

252. It has been said, as an objection to this use of the waste steam, that it offers a much increased resistance to the piston. I cannot, however, admit this to be true if the arrangements are properly adapted, for I have never found, even when the most extensive use has been made of the steam, that it has had any sensible effect on the power of the engine. I always add a contrivance by which the waste steam may either be sent through the warming pipes, &c., or may be diverted and blown directly into the open air; and I have often proved, in presence of many witnesses, that no alteration in the working of the engine was perceptible when this change was made in the disposal of the steam.

253. In many of my arrangements for the purpose now spoken of, I have turned the steam directly from the eduction-pipe into a large receiver, in order to render the blast less perceptible. This vessel should be made of sheet iron or copper, and should be about forty or fifty times the cubic capacity of the cylinder. The pipes conveying the steam away to its various uses should pass from it, and it should also be provided with an escape-pipe leading into the open air, by which the steam may blow away when it is not required for the warming purposes. This last-mentioned pipe should have an enlargement, containing a valve of simple construction, opening outwards (*Klappe*), which may be weighted to about $\frac{1}{4}$ or $\frac{1}{2}$ ℔. on the square inch, so as

to retain the steam in the receiver with this force. It forms then a sort of safety-valve, which will prevent any dangerous increase of pressure in the cylinder, should the ordinary passages become under any circumstances impeded. The diameter of the escape-pipe and of the valve opening should be equal to that of the eduction-pipe of the engine. The water accumulating by condensation in the receiver should be carried away by a syphon-tube, which will not only prevent escape of steam, but also admit air, should a vacuum be formed while the machine is standing still: this last is a very necessary provision.

254. When apartments are to be warmed, the steam should pass, where possible, in a continuous course through pipes laid in the required directions, and with a sufficient fall to carry off the water of condensation: at the end of the circuit the steam should blow by an open pipe into the air. The pipes should be as large as possible, at least twice that of the eduction-pipe of the engine, to give but little hindrance to the passage of the steam; and if no other use but this is made of the steam, the receiver mentioned in the last Article may be dispensed with, taking care, however, to provide the by-pass, to allow the steam to escape directly into the open air when the heating is not required. The heating-pipe and the by-pass may each be furnished with throttle-valves, by which the steam may be turned in either direction at pleasure.

When water or liquids are to be heated, the steam may be led either in a coil of pipe passing through them, or in a jacket surrounding them; or, when circumstances will permit, the steam may be brought at once into the fluid

to be heated, by a dip-pipe, which should have a bend, to cause the steam to discharge itself in a horizontal direction, giving a beneficial motion to the fluid.

For drying apparatus, or the like, flat chambers may be used, taking care to give ample room for the free passage of the steam, and to make due provision for the escape of the condensed water.

In all arrangements of this kind, the steam should be allowed to give out its heat under the least possible pressure, so that the advantage may be obtained without detriment to the action of the engine by raising up a considerable counter-resistance to the piston.

It is certain, that in this particular, as in those more immediately appertaining to the engine itself, there is ample scope for the exercise of that talent, perseverance, experience, and science, which adorn the profession of the Engineer.

255. I close my work with the exhortation of the Apostle—

"PROVE ALL THINGS; HOLD FAST THAT WHICH IS GOOD."

INDEX.

Printed by Hughes & Robinson, King's Head Court, Gough Square.

Boiler for Small Engines.

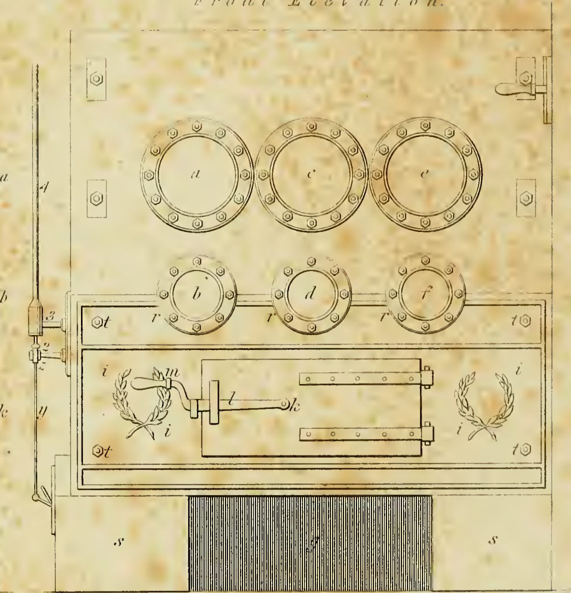
Pl. I.

Fig. 1.

Side Elevation.

Fig. 2.

Front Elevation.



John Weale, 1847.

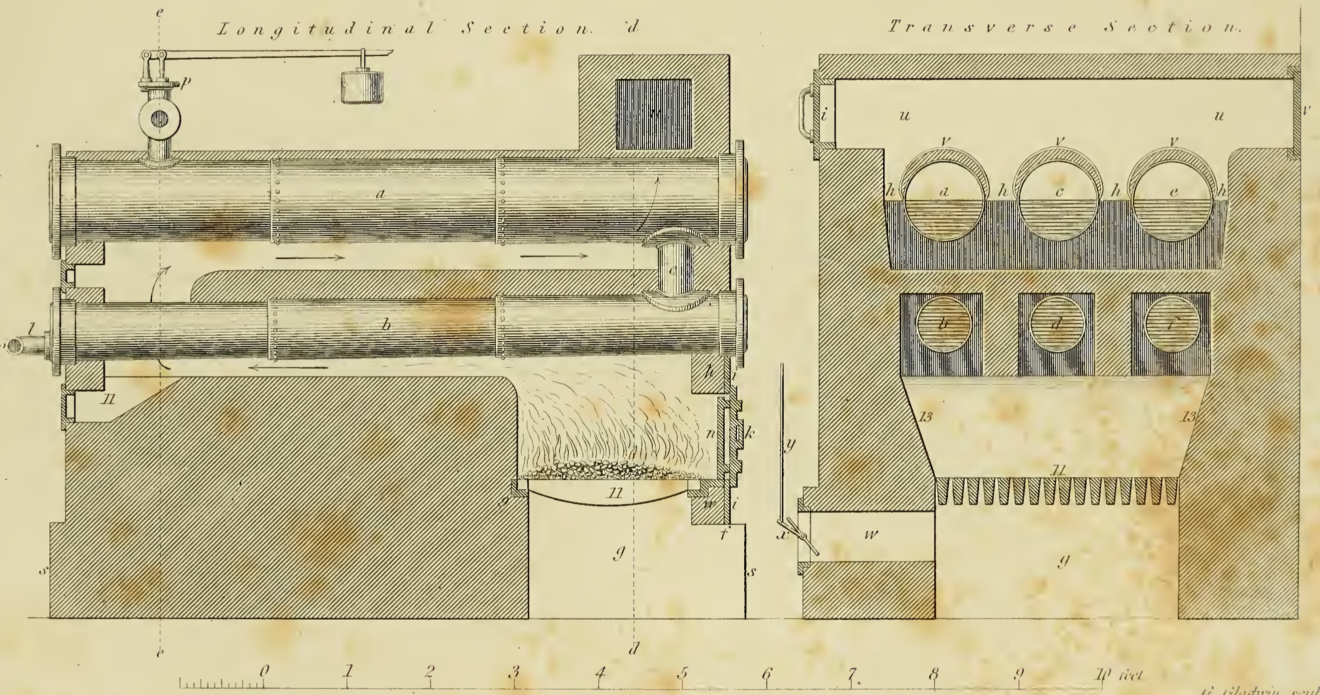
G. Gladwin, sculp.

Boiler for Small Engines.

Pl. II.

Fig. 3. Longitudinal Section.

Fig. 4. Transverse Section.



G. Gladwin, sculp.

John Weale, 1847.

Boiler for Small Engines.

Fig. 5.

Transverse Section.

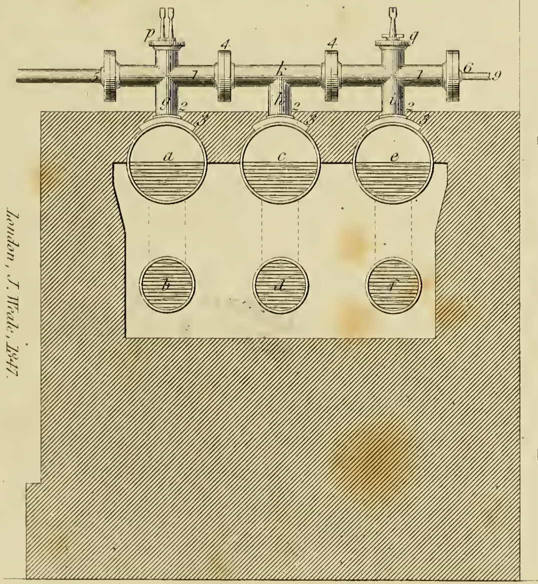
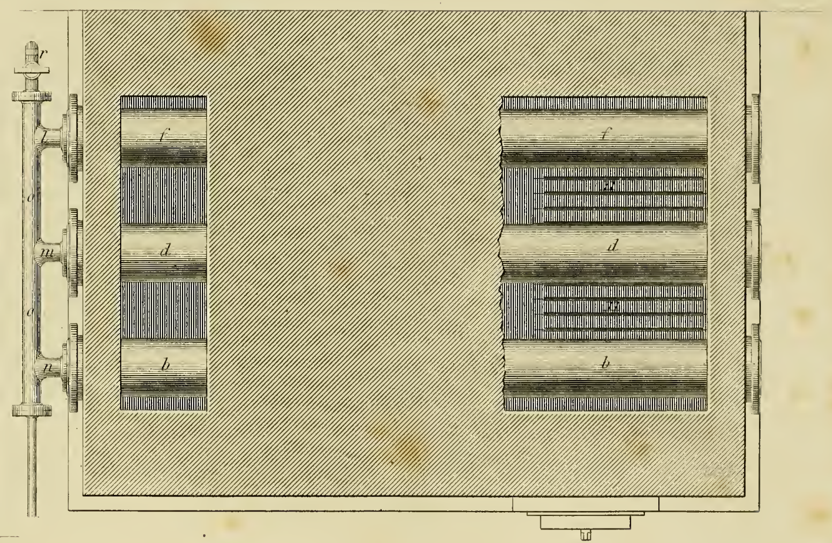


Fig. 6.

Horizontal Section.



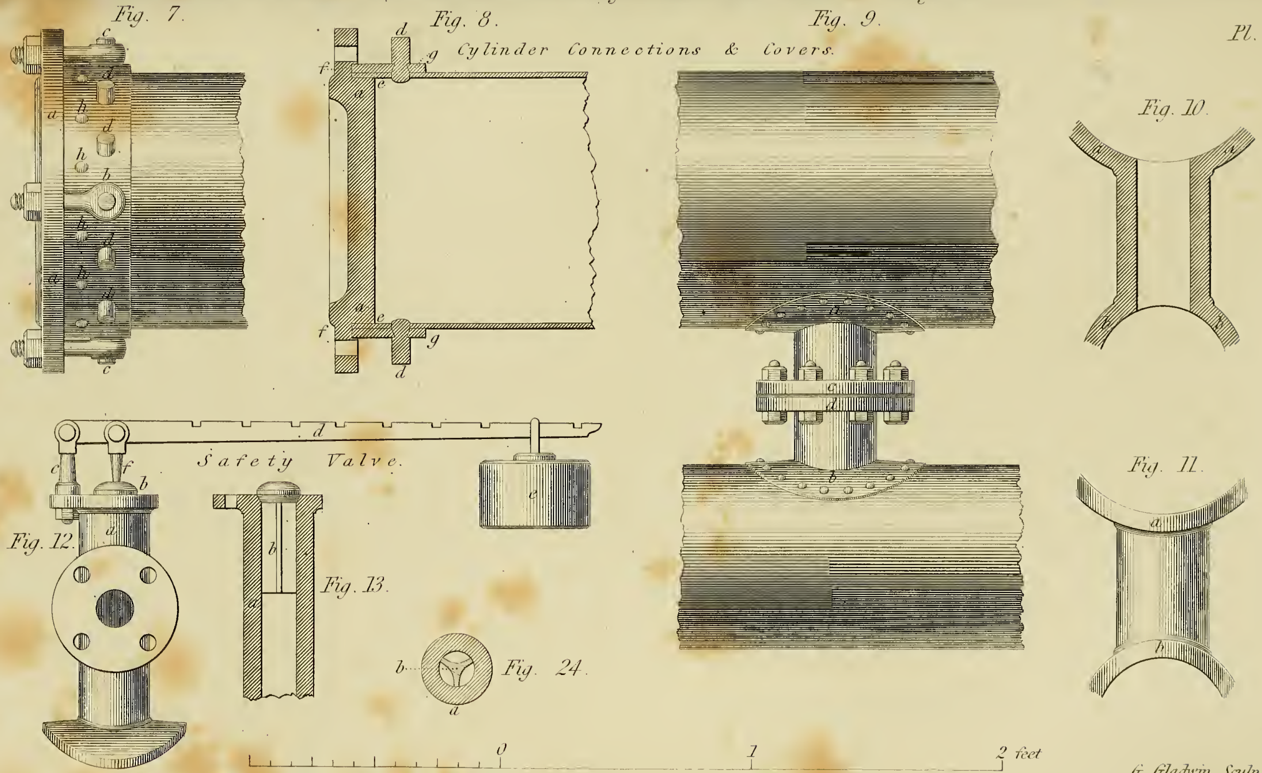
0 1 2 3 4 5 6 7 8 9 10 feet

London, J. Weale, 1847.

G. Gladwin, Sculp.

Details of Boiler & safety valve for Small Engines.

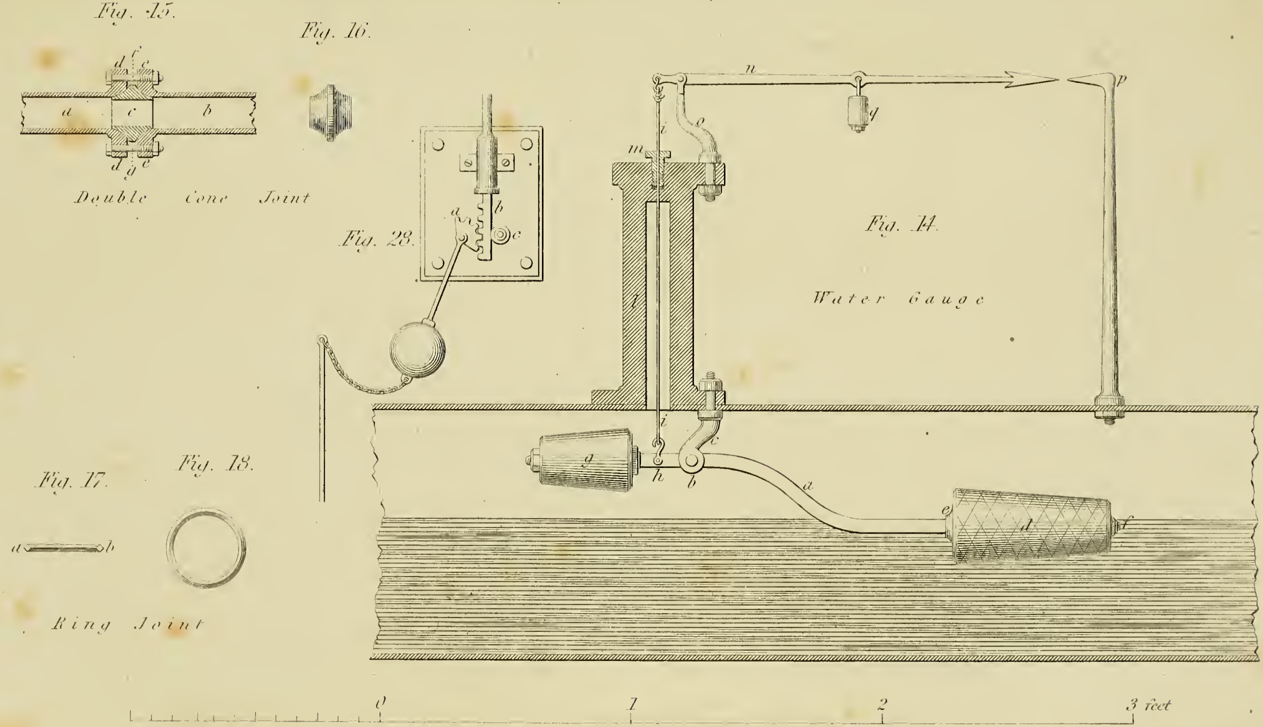
Pl. IV.



London, J. Weale, 1847.

G. Gladwin, Sculp.

Details of Water Gauge & Joints.

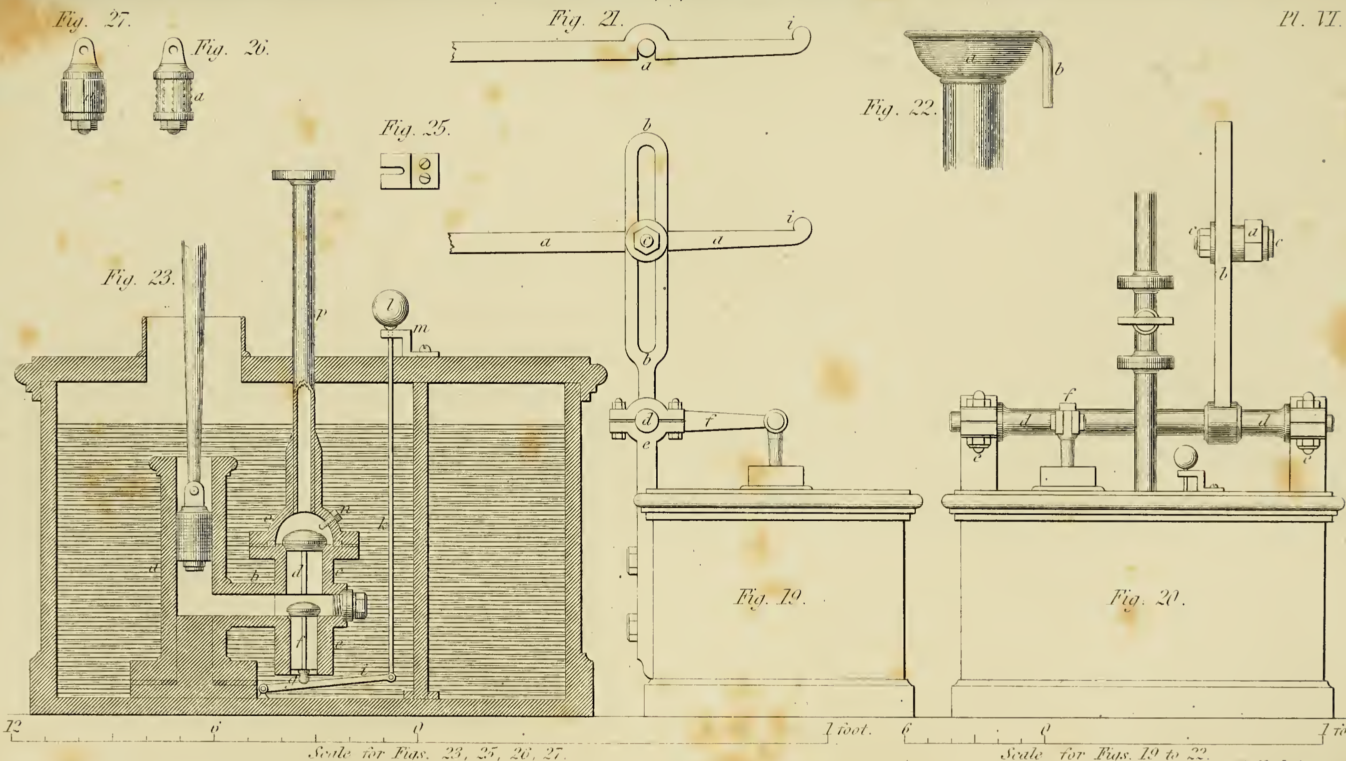


John Weale, 1847.

G. Gladwin, sculp.

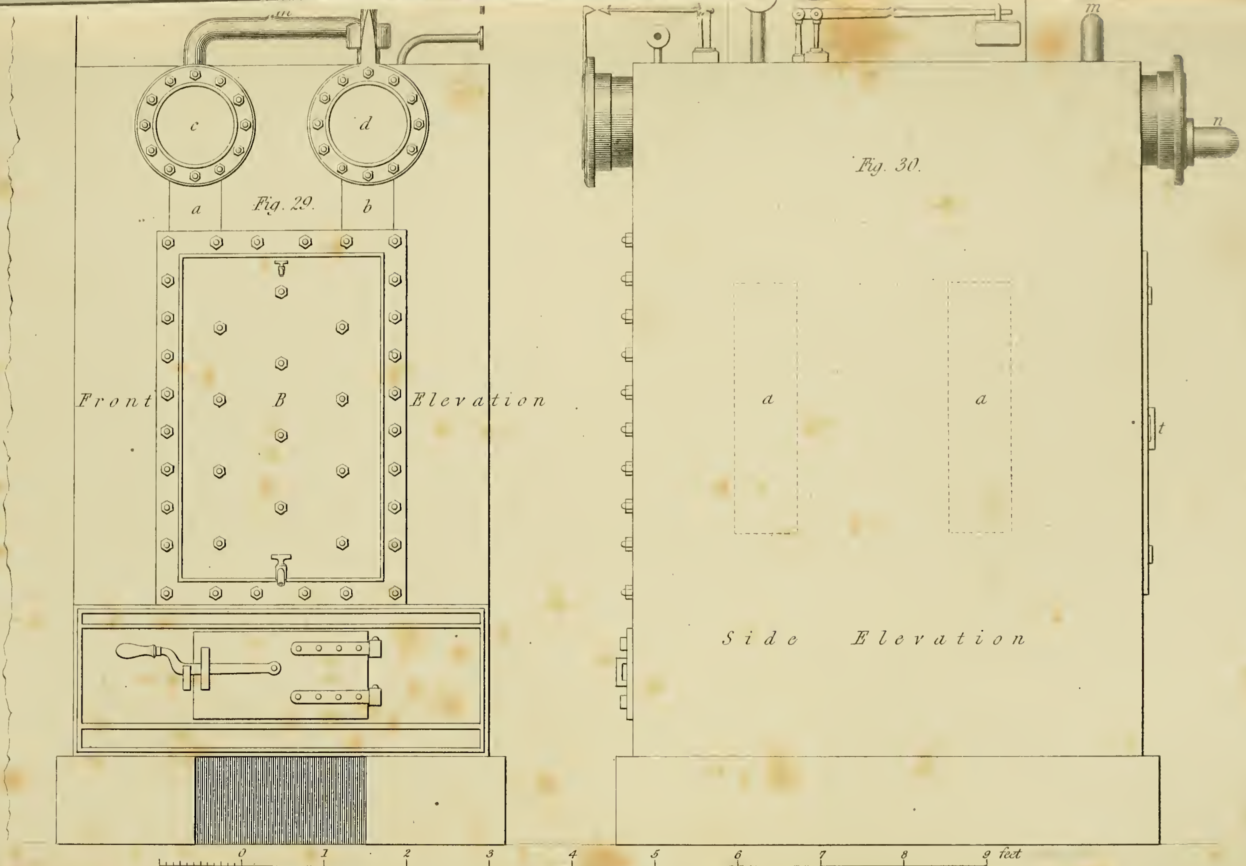
Feed Apparatus.

Pl. VI.



John Weale, 1847.

G. Gladwin, sculp.



John Weale, 1848.

G. Gladwin, sculp.

Fig. 31.

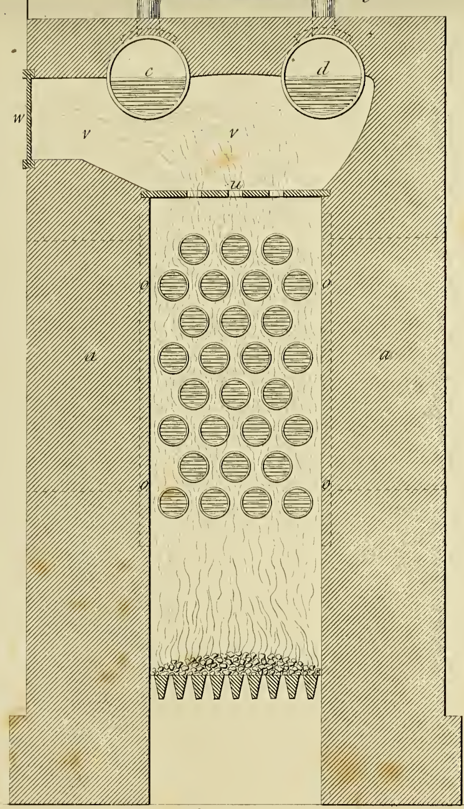
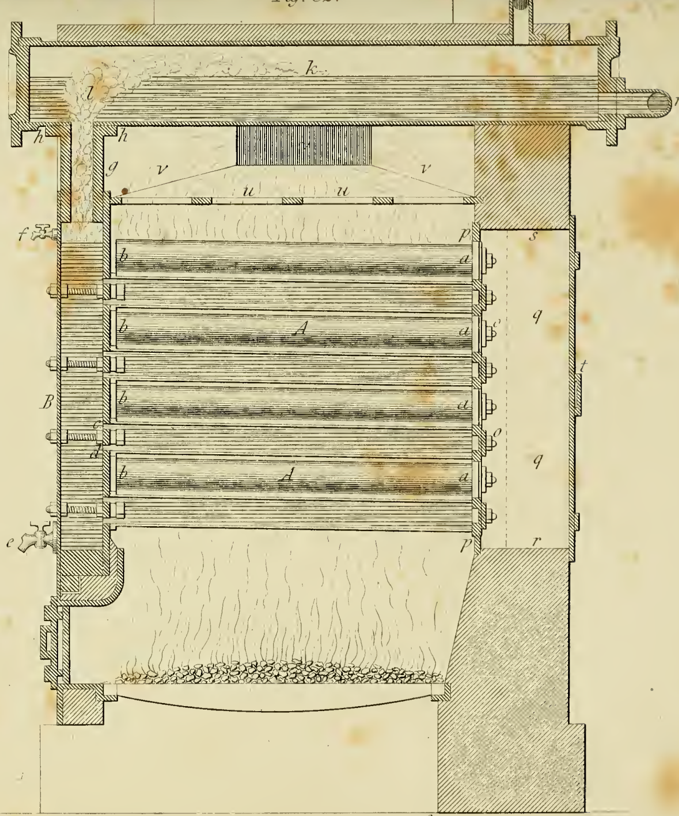


Fig. 32.

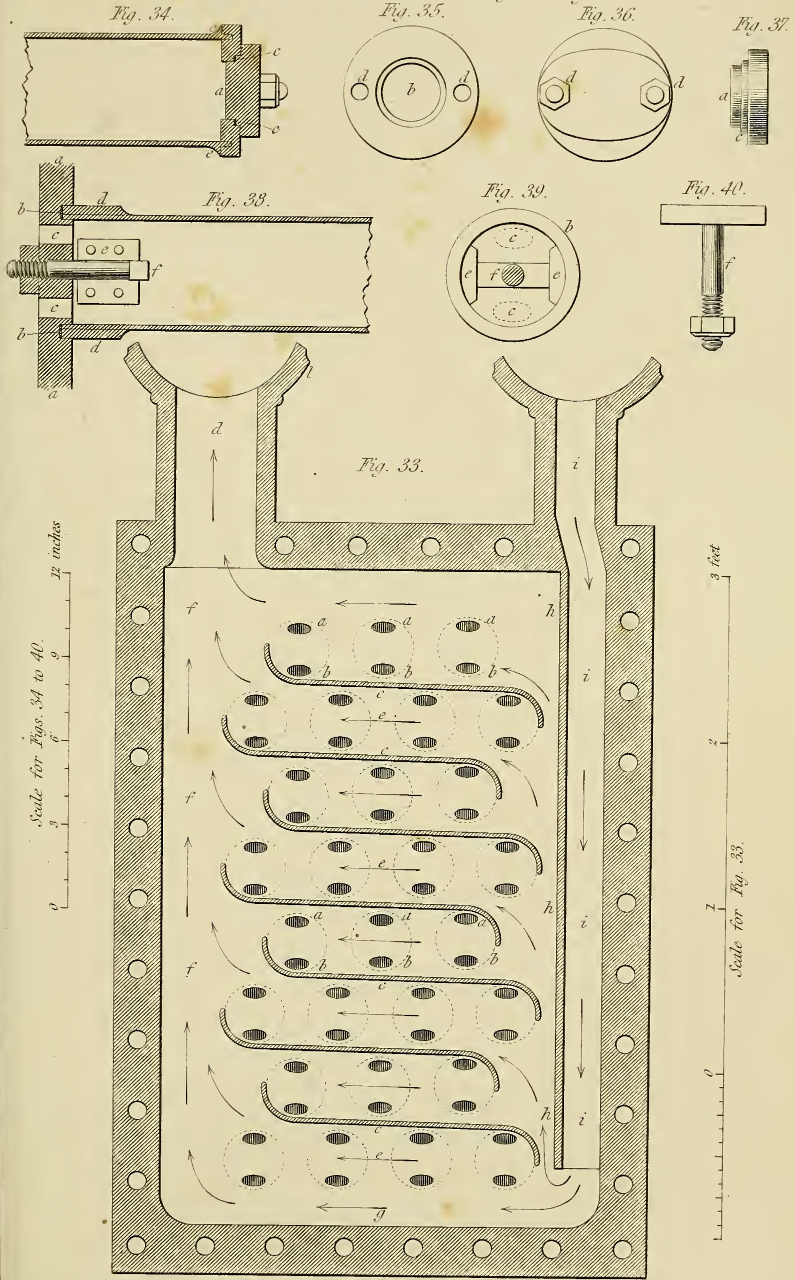


0 1 2 3 4 5 6 7 8 9 Feet

John Weale, 1848.

G. Gladwin, sculp.

Details of Boiler for Large Engines. Pl. 9.



John Weale, 1848. G. Gladwin, sculp.

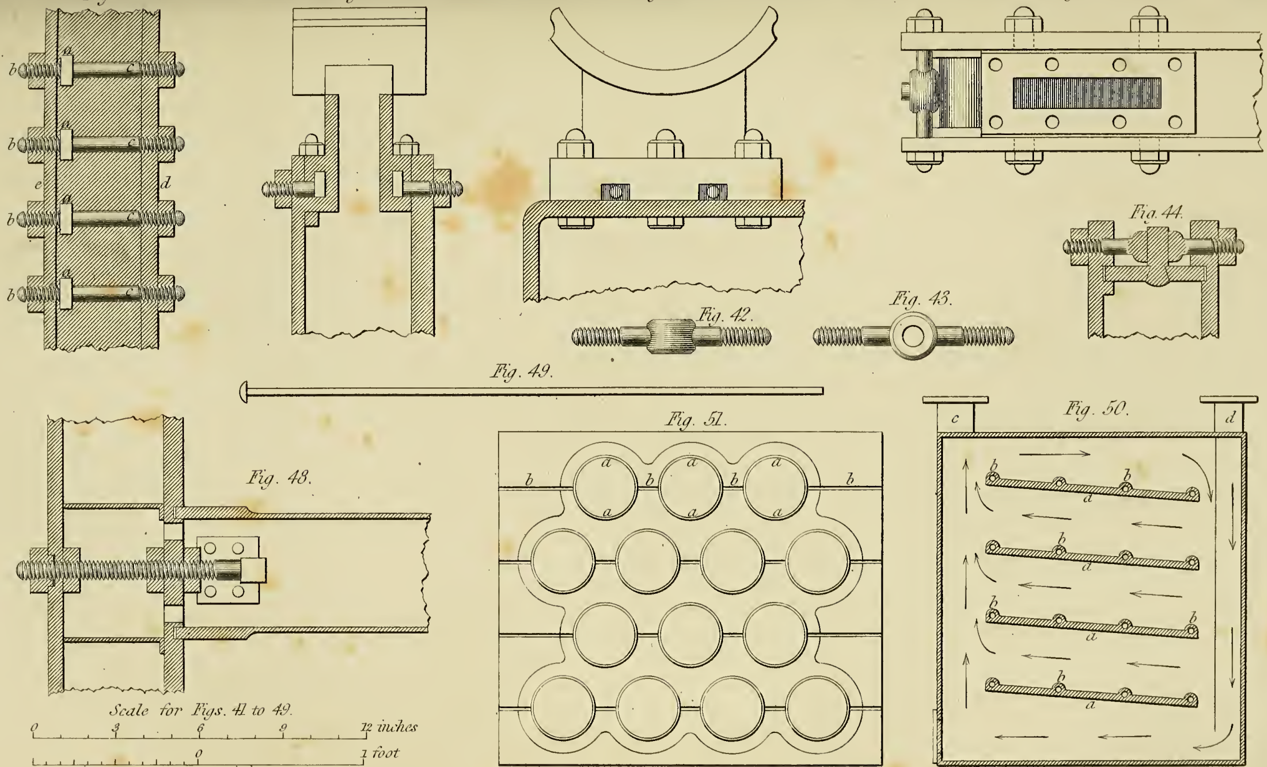


Fig. 41. Fig. 42. Fig. 43. Fig. 44. Fig. 45. Fig. 46. Fig. 47. Fig. 48. Fig. 49. Fig. 50. Fig. 51.

John Weale, 1848.

G. Gladwin, sculp.

Plan of water connecting tubes.

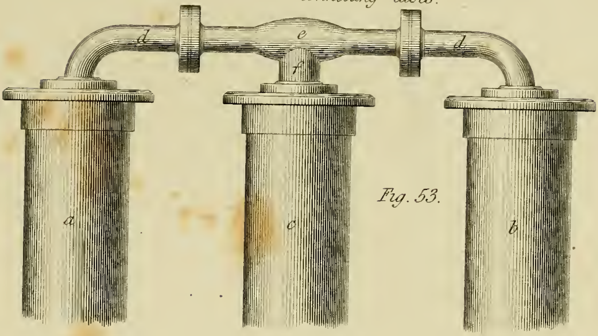


Fig. 53.

Views of a Thirty-horse Boiler.

Front Elevation.

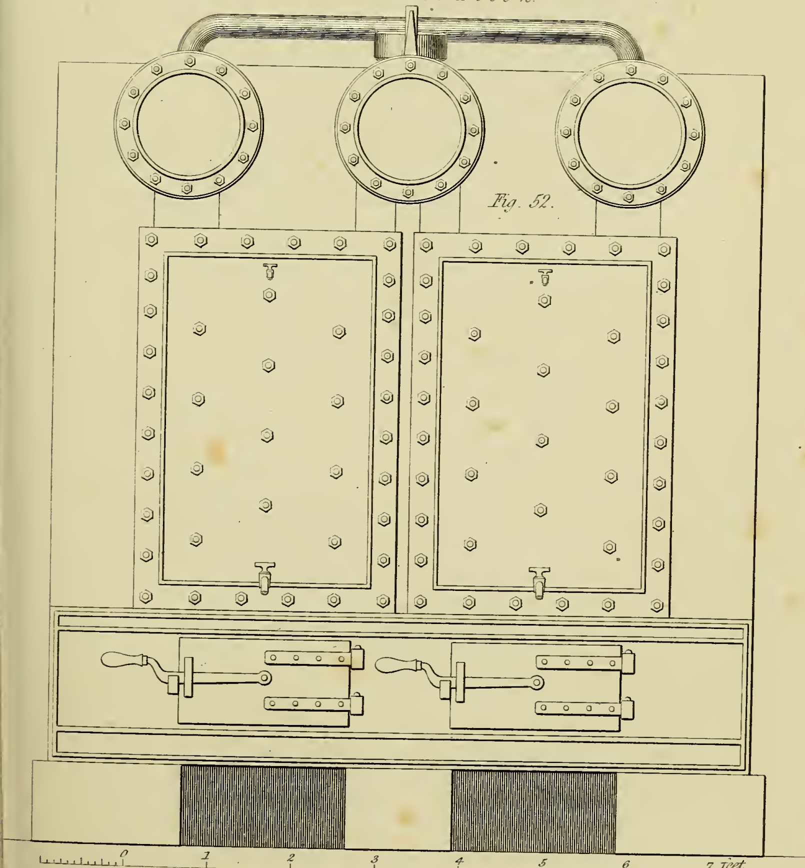
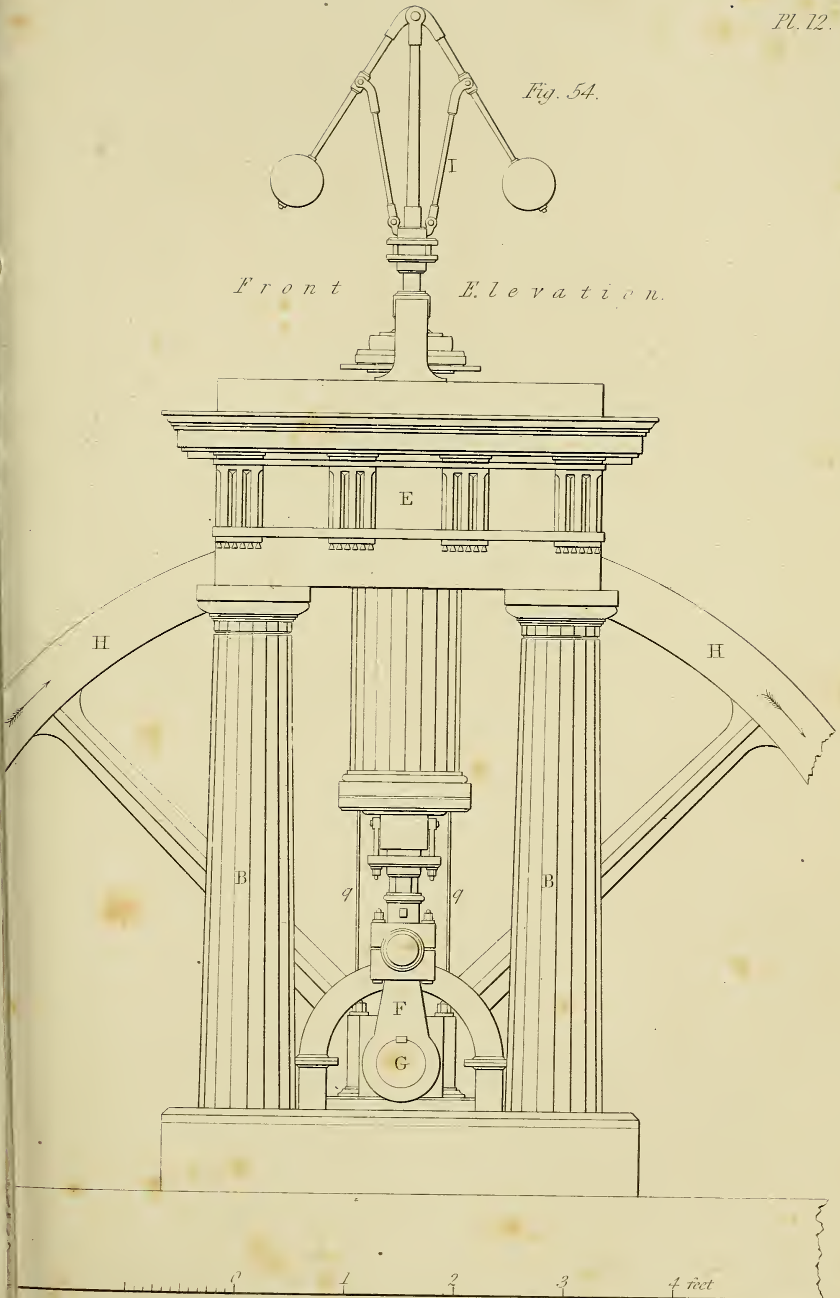


Fig. 52.

John Weale, 1848.

G. Gladwin, sculp.

Fig. 54.



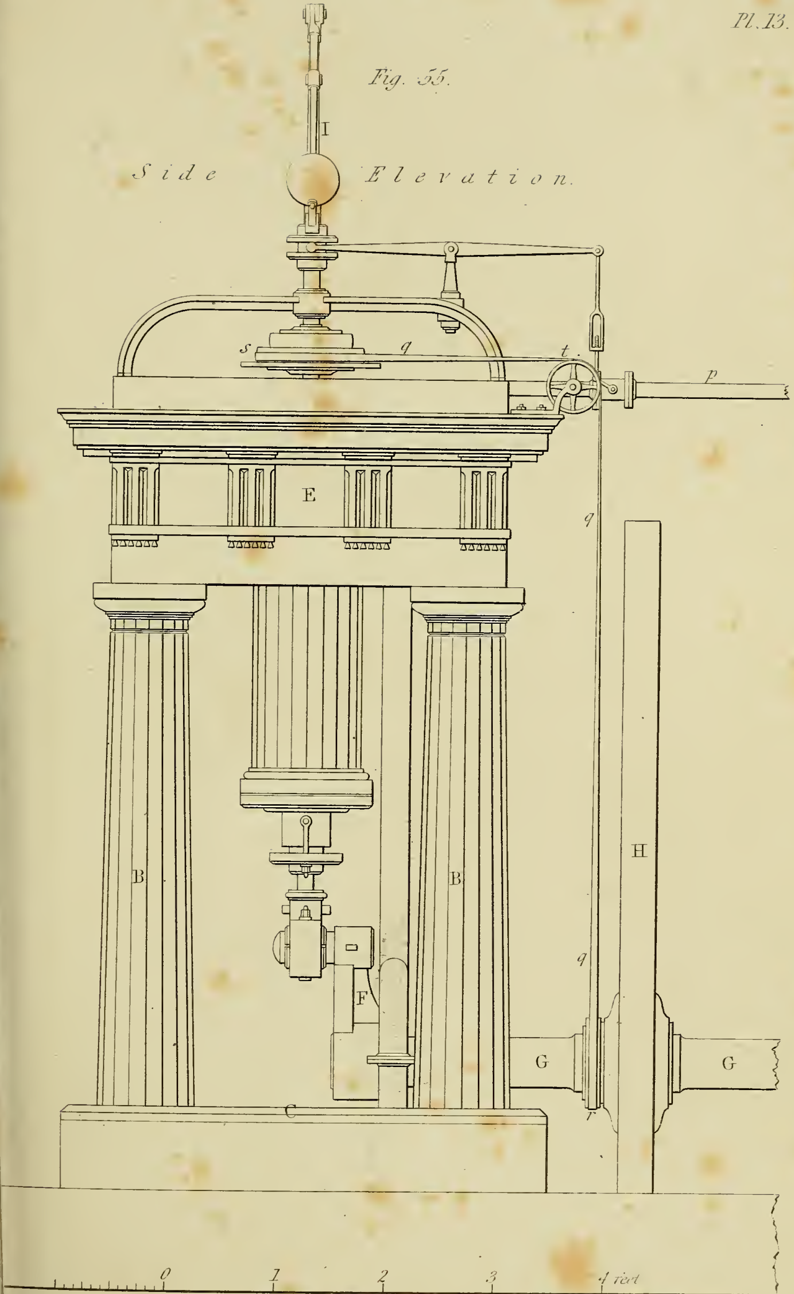
J. Weale. 1848.

G. Gladwin, sc.

Pl. 13.

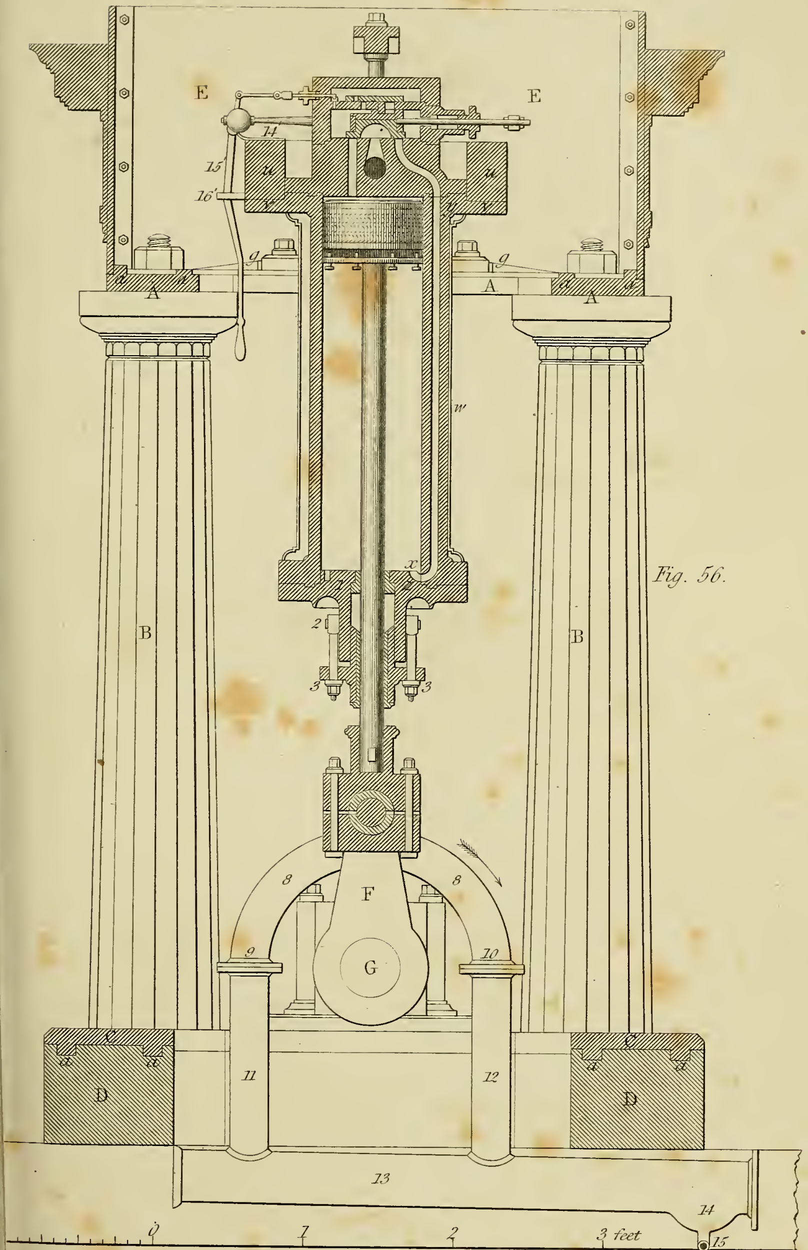
Fig. 55.

Side Elevation.

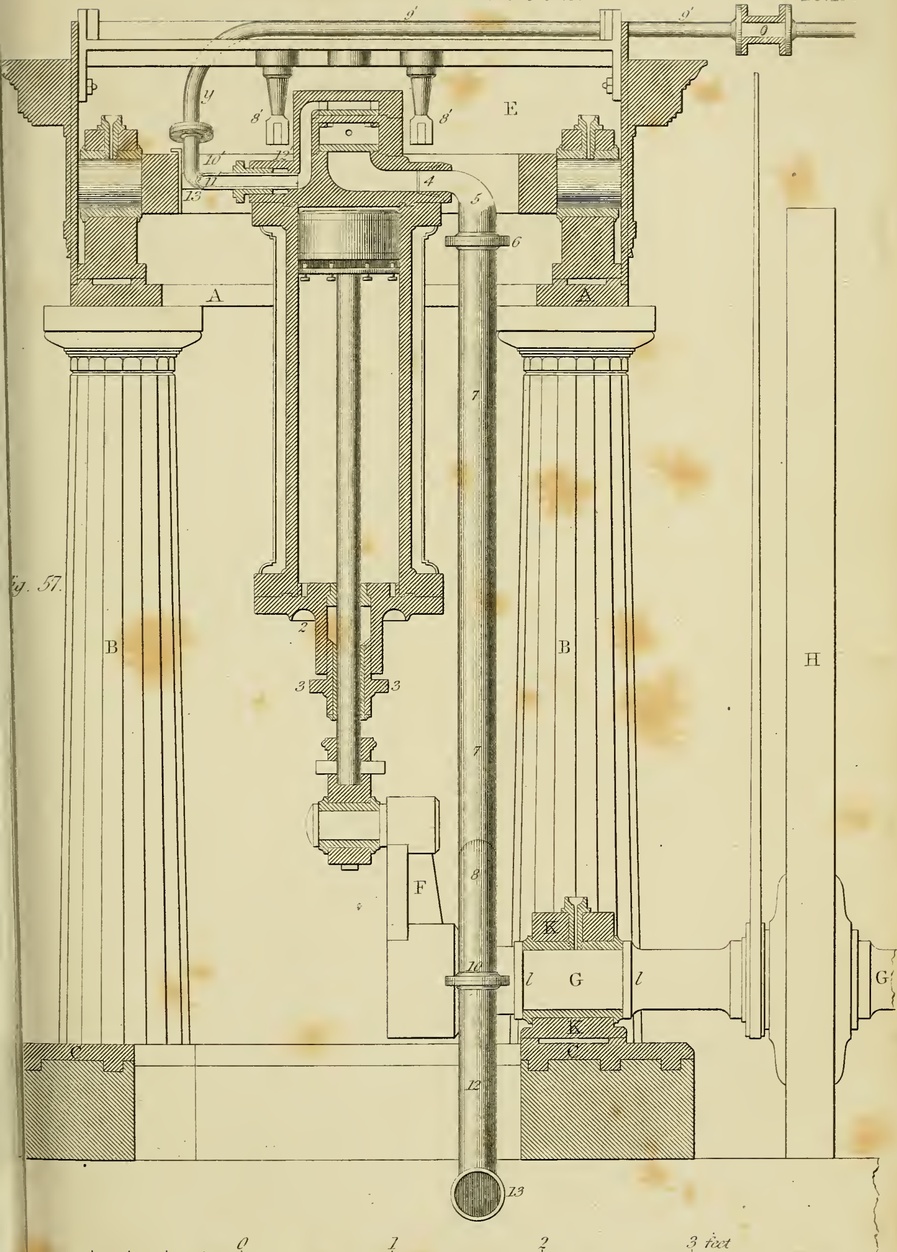


J. Weale, 1848.

G. Gladwin, sc.



J. Weale, 1848. G. Gladwin, sc.

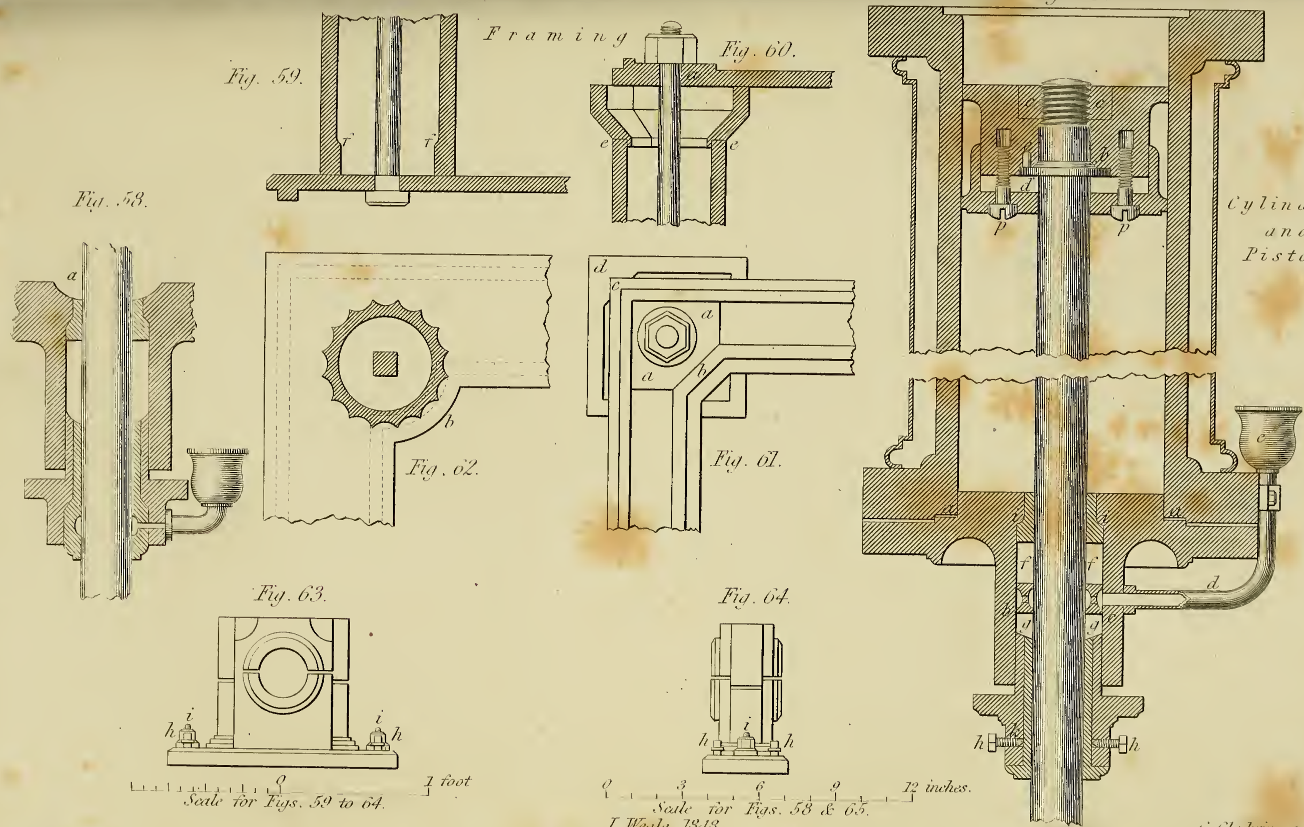


J. Weale, 1848.

G. Gladwin, sc.

Details.

Pl. 16.



J. Weale, 1848.

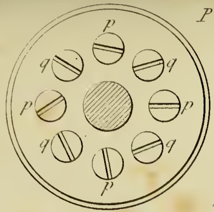
G. Gladwin, sc.

D e t a i l s.

Pl. 17.

Fig. 66.

P i s t o n



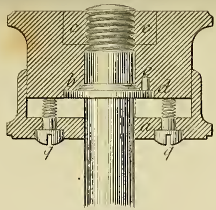


Fig. 67.

Fig. 72.

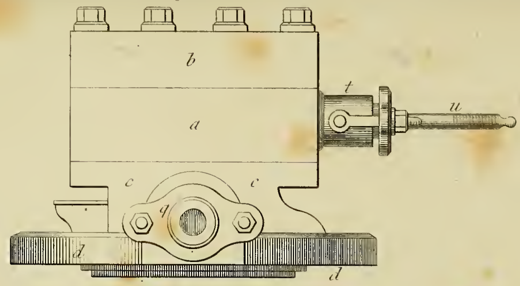


Fig. 68.

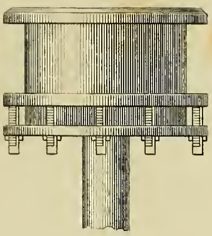


Fig. 70.

Swing Frame

Upper Cylinder, cover & Valve boxes.

Fig. 69.

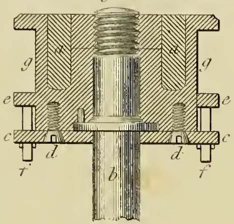
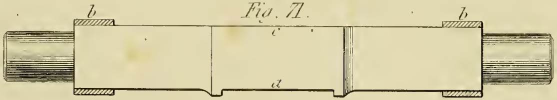


Fig. 71.

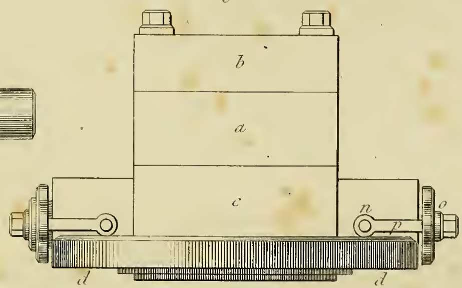


0 1 2 feet
Scale for Figs. 70 & 71.

0 6 12 inches
Scale for Figs. 66, 67, 68, 69, 72 & 73.

J. Weale, 1848

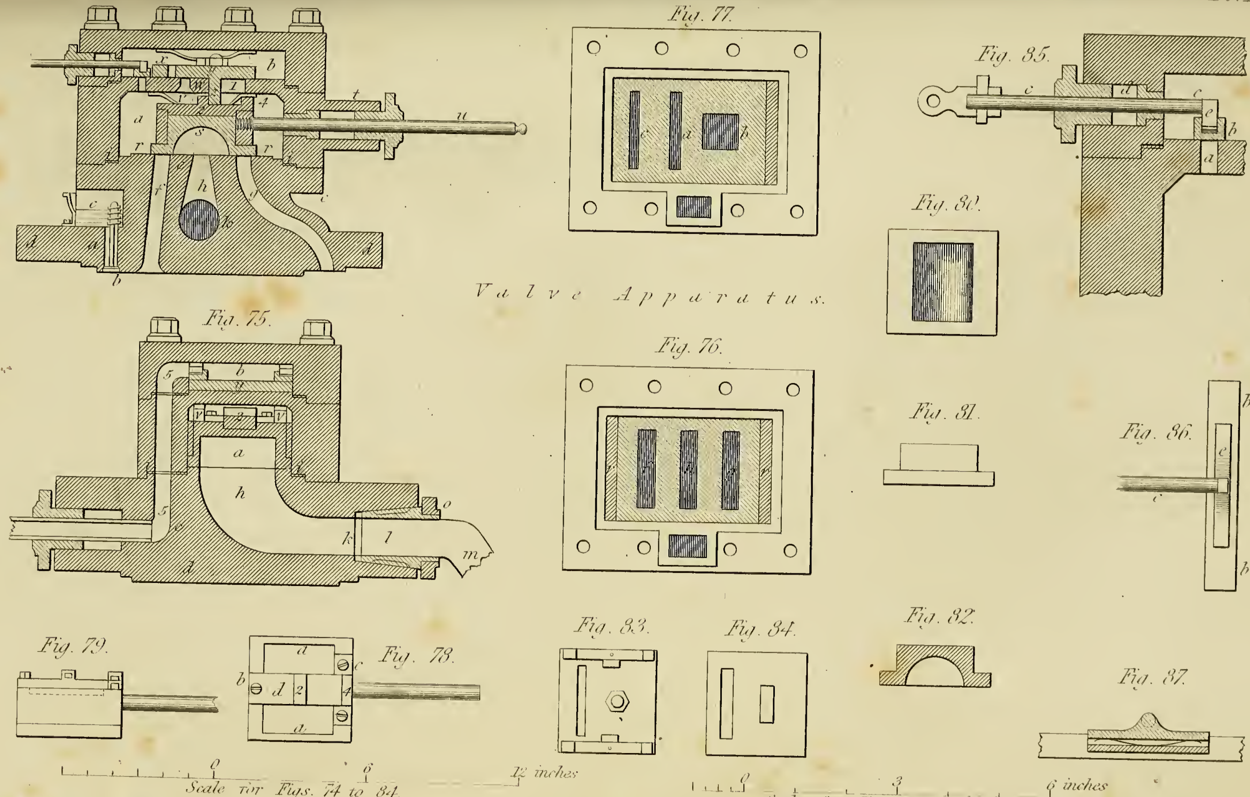
Fig. 73.



G. Gladwin, sc.

Details.

Valve Apparatus.



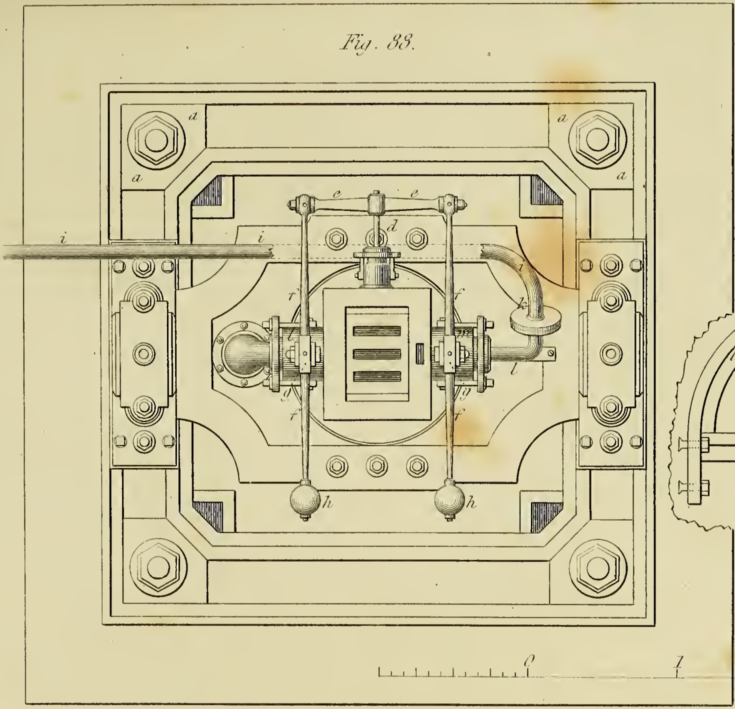
J. Weale, 1848.

G. Gladwin, sc.

Details.

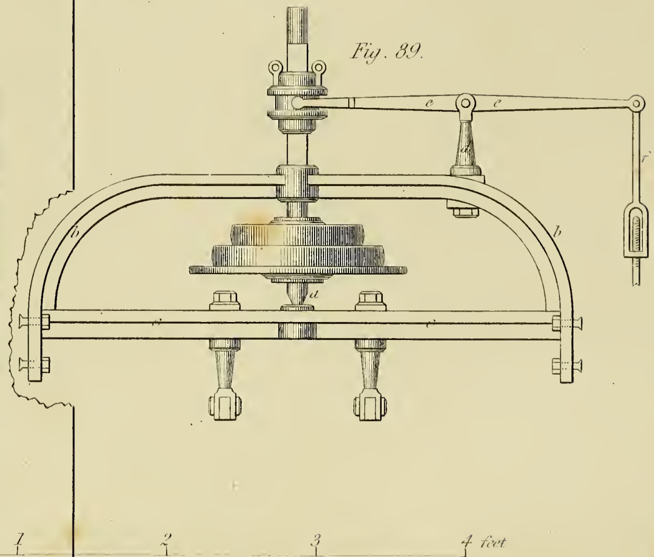
Plan of Entablature Box, &c.

Fig. 88.



View of Cross Bridge, & apparatus attached to it.

Fig. 89.



J. Weale, 1843

G. Gladwin. sc.

Fig. 90.

№ 1. № 2. № 3. № 4.

Diagrams explaining the action of the Valves.

№ 5. № 6. № 7. № 8.

Fig. 93.

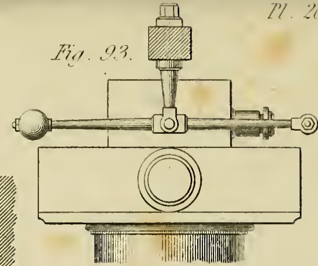


Fig. 94.

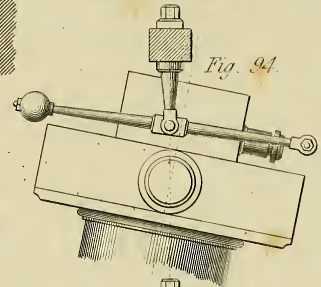
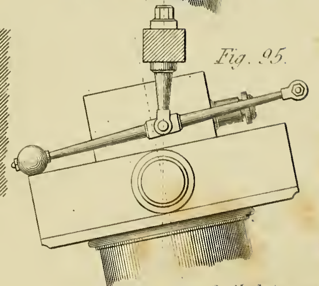


Fig. 95.



0 3 6 9 12 inches
Scale for Fig. 90.

0 1 foot
Scale for Figs. 93, 94, 95.

J. Weale, 1848.

G. Gladwin sc.

Details.

Modification of the expansion slide.

Fig. 91.

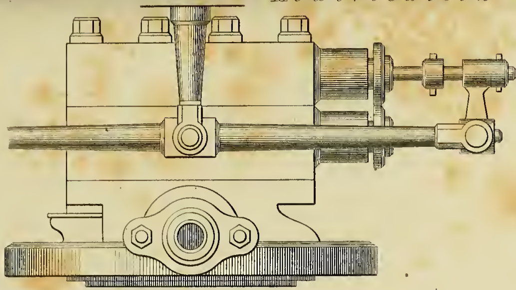
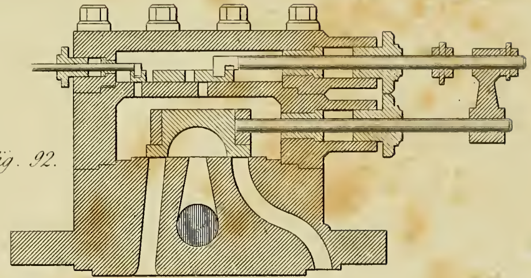


Fig. 92.



Condenser.

Fig. 97.

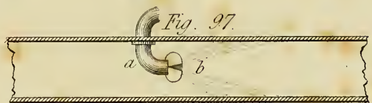
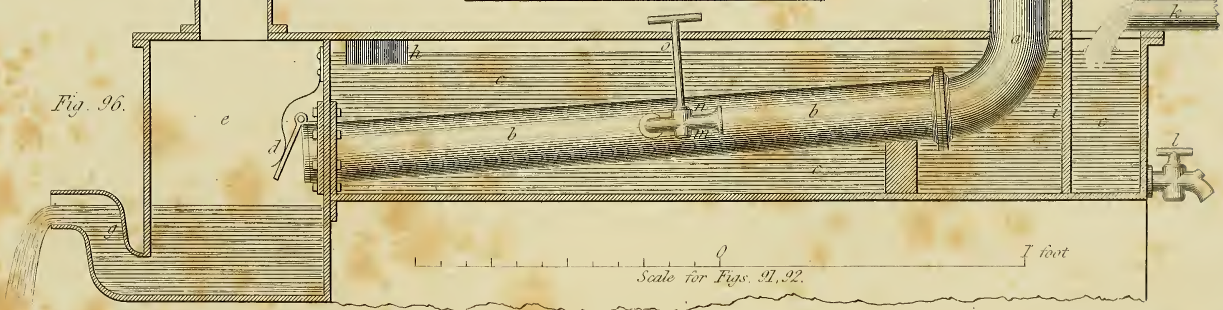


Fig. 96.



J. Weale, 1848.

G. Gladwin

Modification of the Oscillating Engine.

Pl. 22

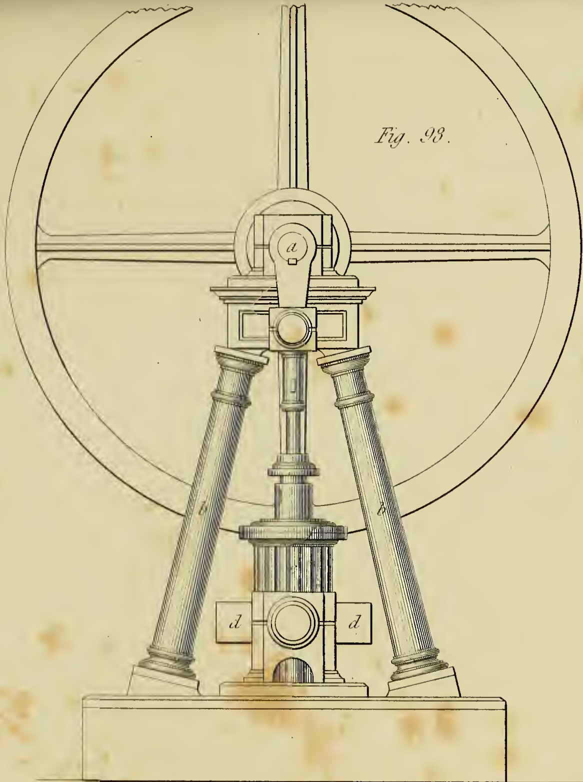


Fig. 98.

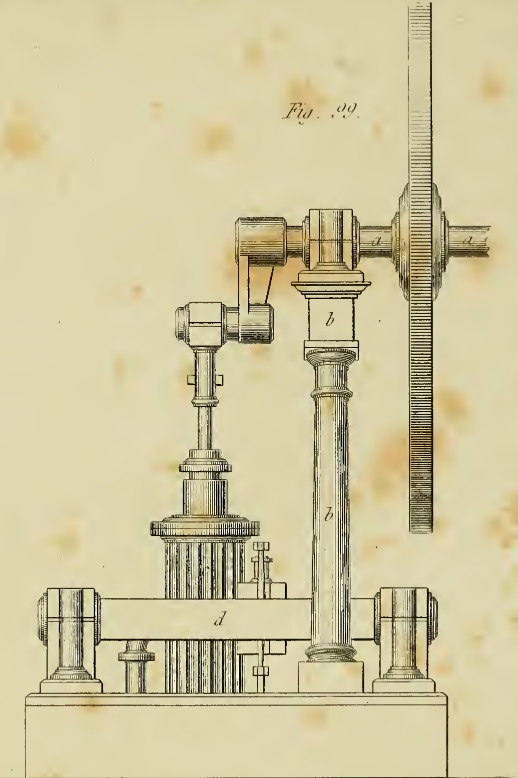


Fig. 99.

J. Weale, 1848.

G. Gladwin, sc

Fig. 100.

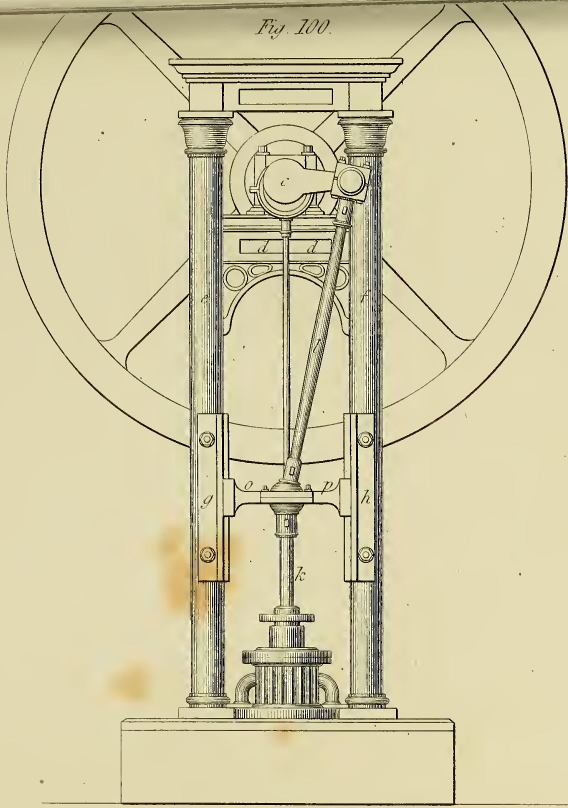


Fig. 113.

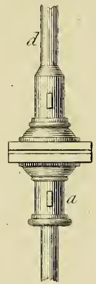


Fig. 114.

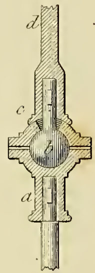
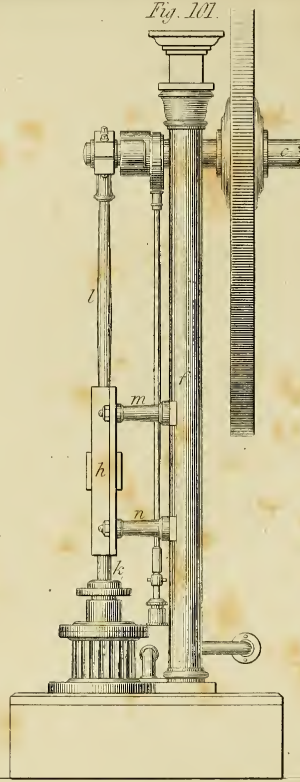


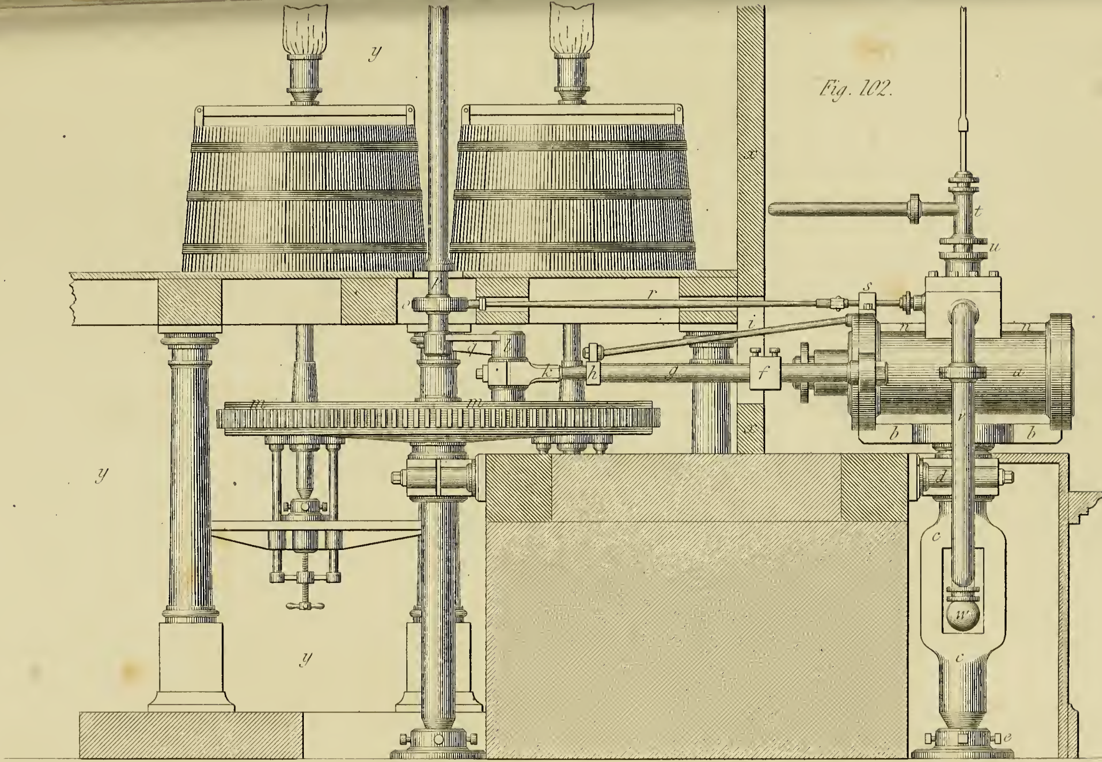
Fig. 101.



J. Weale, 1848.

G. Gladwin, sc.

Fig. 102.



J. Weale, 1848. G. Gladwin sc.

Single acting Pumping Engine.

Fig. 103.

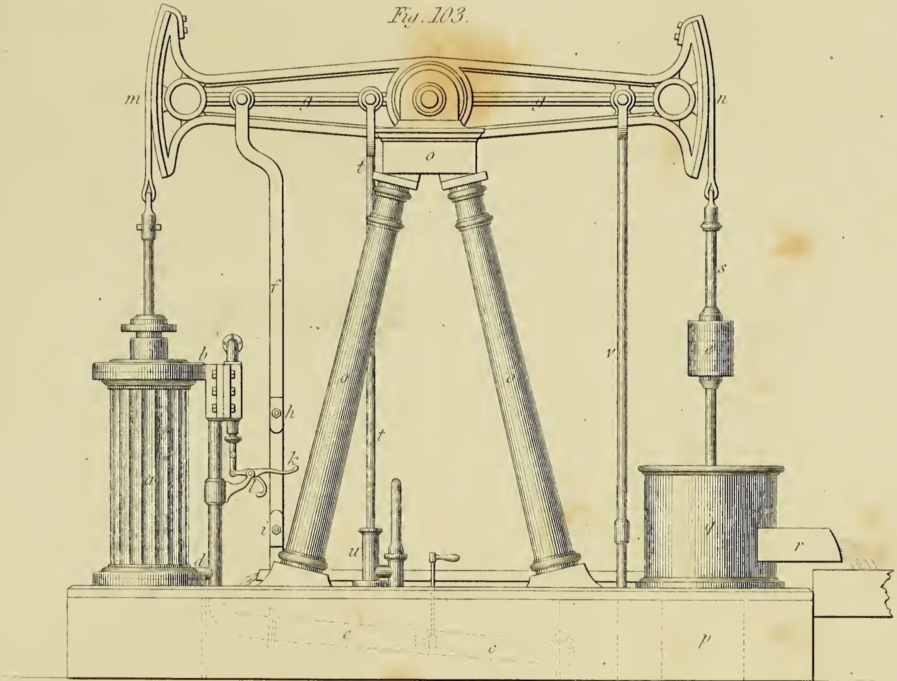
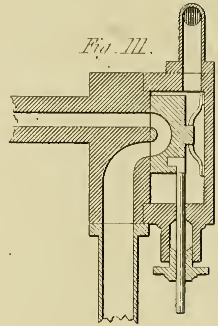


Fig. 111.



Valves, enlarged.

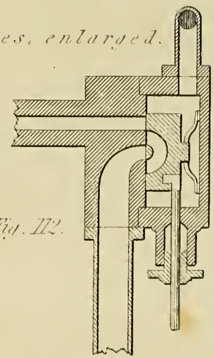


Fig. 112.

J. Weale, 1848.

G. Gladwin sc.

Single acting Pumping Engine.

Fig. 104.

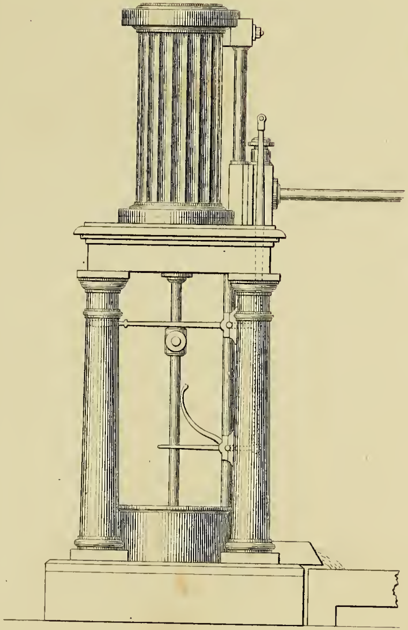


Fig. 105.

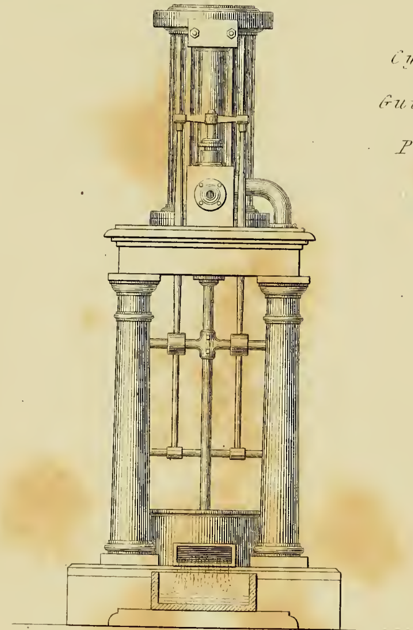
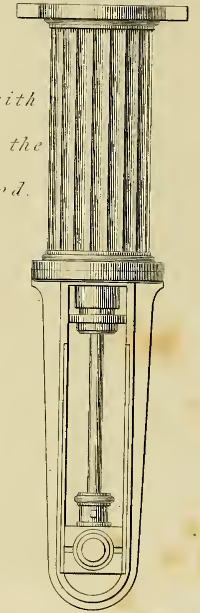


Fig. 110.



Cylinder with Guides for the Piston Rod.

J. Weale, 1848.

G. Gladwin, sc.

Oscillating Engines for a Steam Vessel. Pl. 27.

Fig. 106.

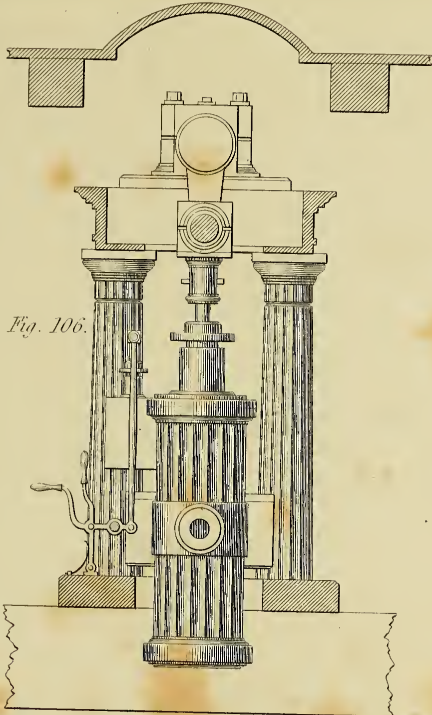
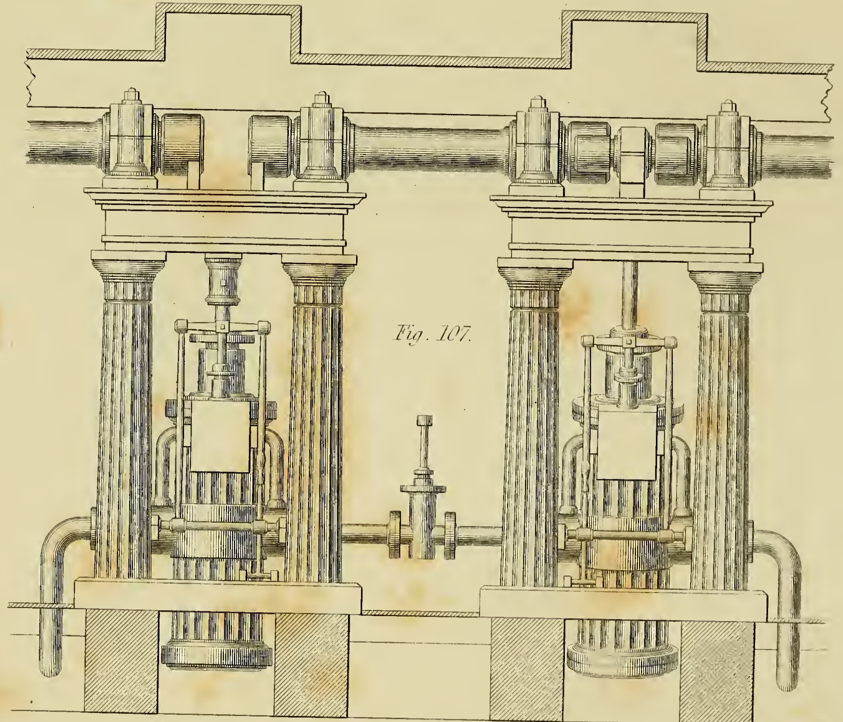


Fig. 107.



J. Weale, 1848.

G. Gladwin sc

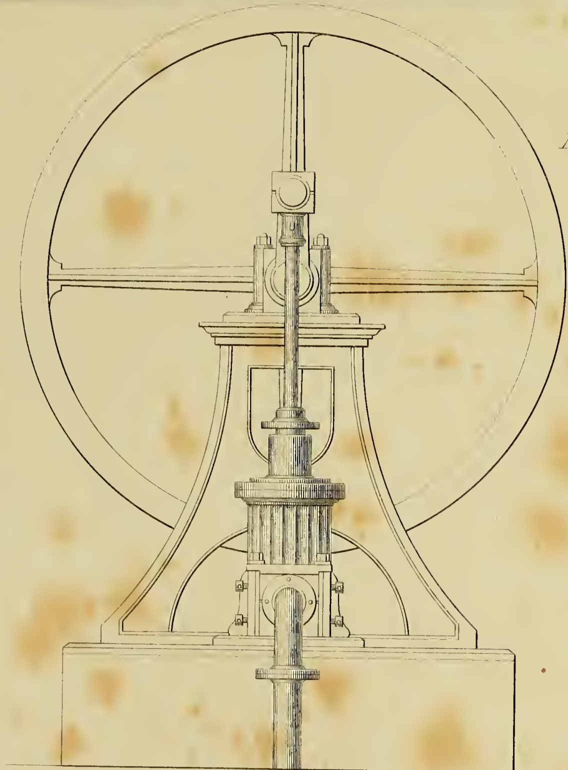


Fig. 108.

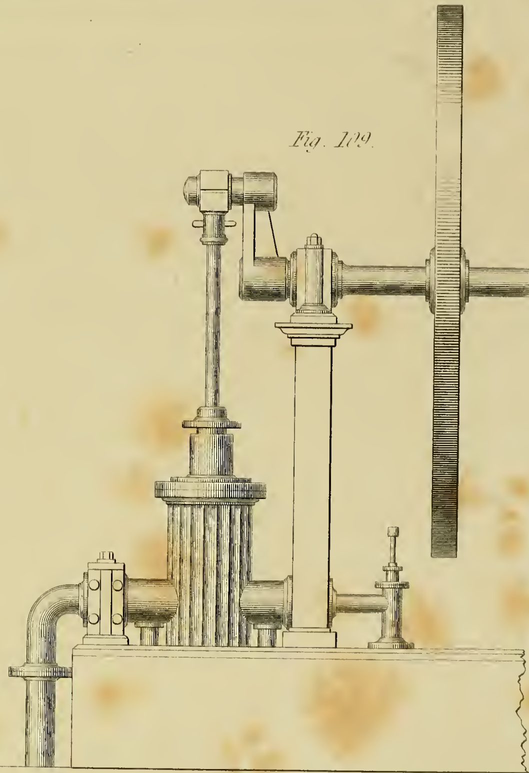


Fig. 109.

J. Weale, 1843.

G. Gladwin. sc

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